UNIVERSITY OF TORONTO LIBRARY
3 1761 00025072 0

ENGINEERING WONDERS OF THE WORLD

EDITED BY ARCHIBALD WILLIAMS

3 wb
£3/3/-
178

ENGINEERING WONDERS
OF THE WORLD

VOLUME I.

ENGINEERING WONDERS OF THE WORLD

EDITED BY

ARCHIBALD WILLIAMS

VOLUME I.

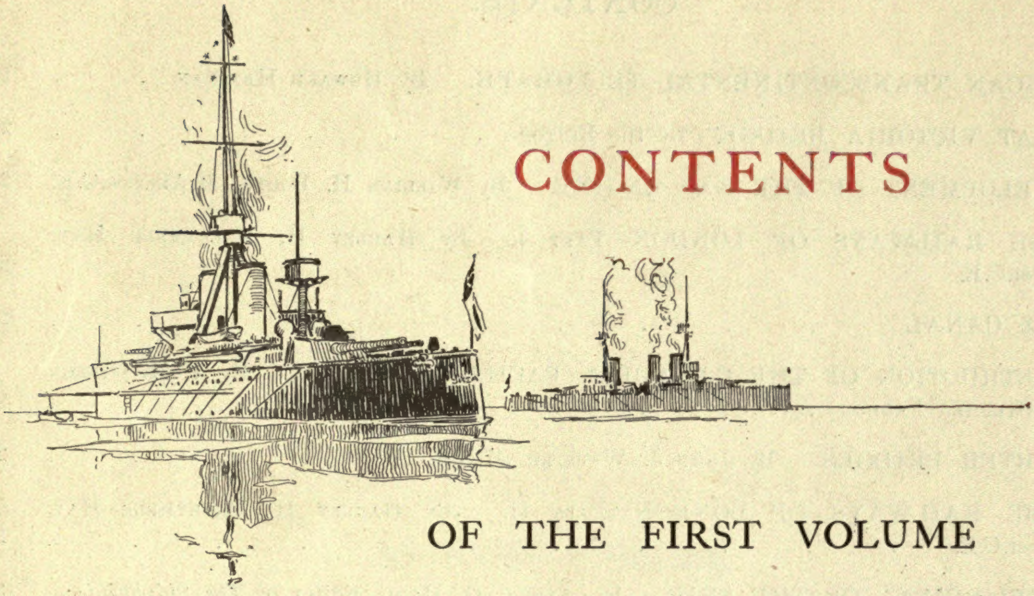
With 520 Illustrations, Maps, and Diagrams

THOMAS NELSON AND SONS

London, Edinburgh, Dublin, and New York

LIBRARY
NOV 17 1969
UNIVERSITY OF TORONTO

TA
15
W5
v.1



CONTENTS

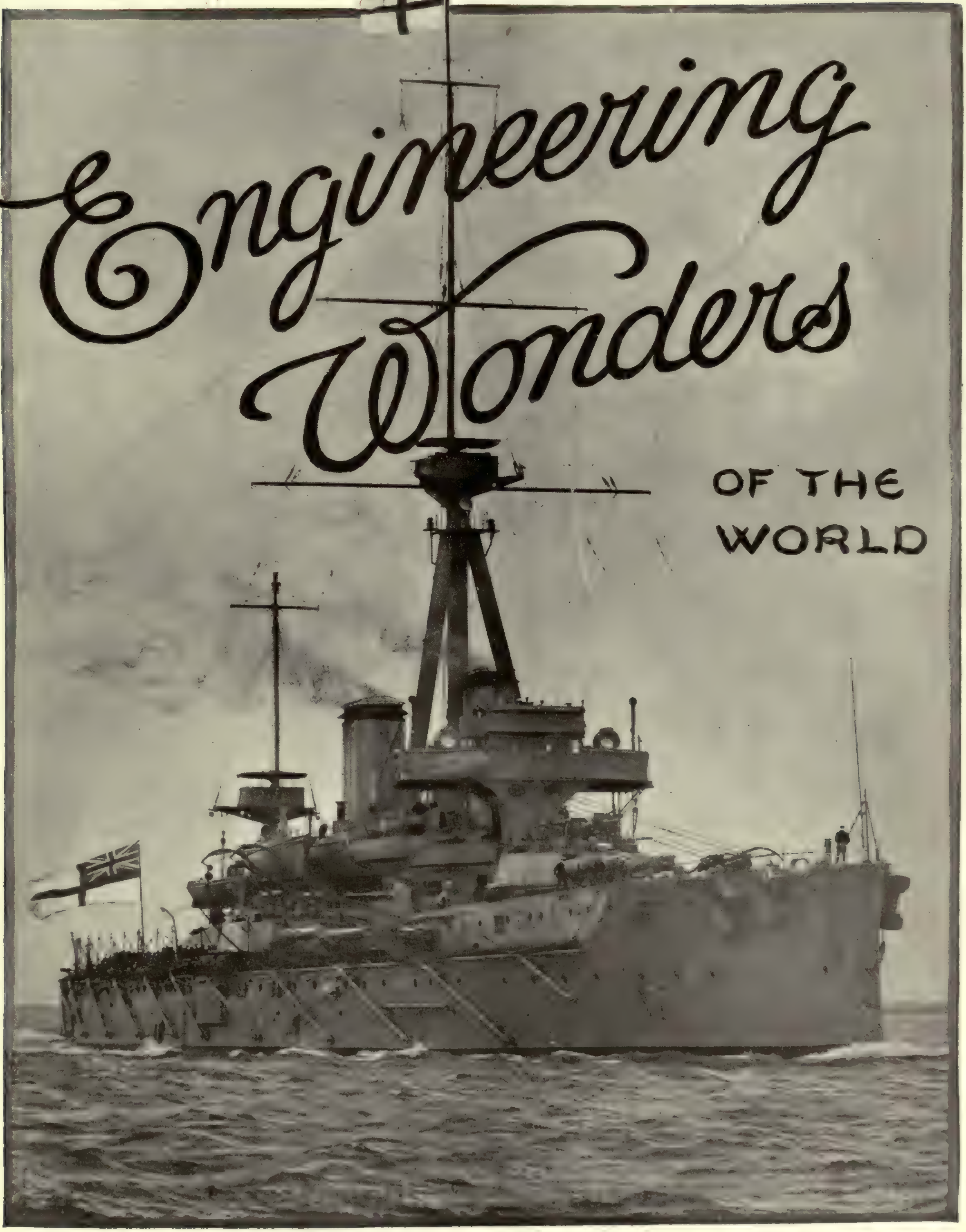
OF THE FIRST VOLUME

LIST OF COLOURED PLATES

IN THIS VOLUME

PROSPECTUS

Engineering Wonders OF THE WORLD



THOMAS NELSON AND SONS

SPECIMEN PLATE.

BUILDING THE FORTH BRIDGE.

This is a reproduction in Black-and-White of one of the numerous Coloured Flates.

" WORK."

From the Picture by Ford Madox Brown.

A FASCINATING STORY.

THERE is no more fascinating reading in the world than the story of machinery and what it has accomplished for the benefit of mankind. "Man," said Carlyle, "is a tool-using animal. Weak in himself, and of small stature . . . feeblest of bipeds! . . . Nevertheless he can use tools, can devise tools. With these the granite mountain melts into light dust before him; he kneads glowing iron as if it were soft paste; seas are his smooth highway, wind and fire are his unwearying steeds."

Think for a moment of the achievements of that most important of tools, the steam engine. It unlocks the secret mine, it fashions a screw shaft, it makes a pin, it spins, it weaves, it ploughs, it threshes and grinds corn, it fells trees and slices them into planks, it sets a hundred machines going under one roof, it whirls us along faster than the fleetest racehorse, it draws infinite power and illumination from the dynamo, and at the will of the mechanician its touch can be made more delicate than a lady's finger or more overwhelming than the grip of a giant.

A MODERN "SKY-SCRAPER."

Not the least interesting articles are those that describe the erection and construction of steel-framed and "ferro-concrete" buildings.

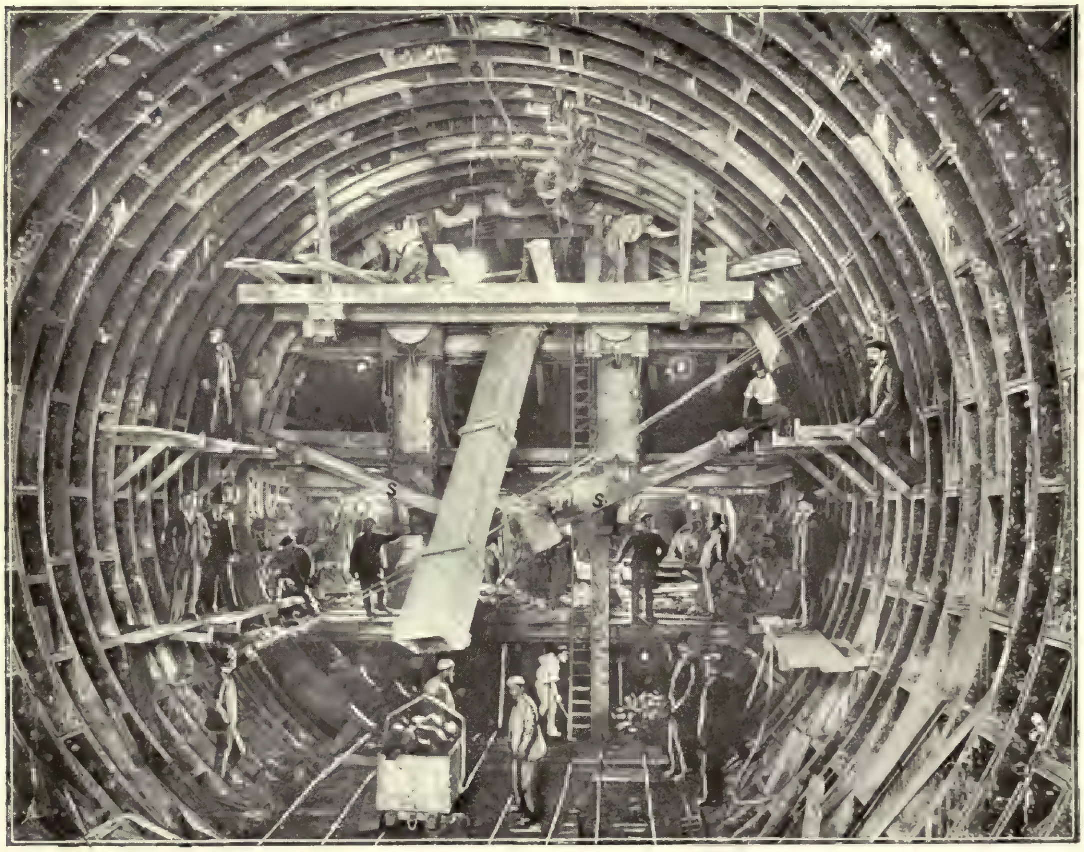
Then think of the masterly ingenuity and skill with which "the feeblest of bipeds" has devised the countless machines which are daily actuated by steam, electricity, compressed air, or hydraulic force.

MODERN MIRACLES.

Go a step further, and conceive all this power and this varied machinery harnessed and directed to the accomplishment of such modern miracles of engineering as the *Panama Canal*, the *Forth Bridge*, the *Simplon Tunnel*, the *Assouan Dam*, the *White Pass Railway*, the *London Tubes*, the *Niagara Water Power Stations*, a *Dreadnought* or a *Mauretania*. No man with a spark of intelligence or of interest in the progress of the world can possibly be insensible to the fascination of such colossal monuments of human achievement. We live in an age of engineering, and there is no poet great enough to write its epic.

A RECORD OF PROGRESS.

For one man who is interested in the advance of metaphysics, medicine, or pure mathematics, a thousand are interested in the progress of engineering science, for it not only stimulates popular curiosity, but directly concerns popular comfort, convenience, and efficiency. Yet the average man is woefully ignorant of these matters. Ask the first half-dozen intelligent citizens you meet to explain to you in simple language the principles involved in the *Turbine*, *Wireless Telegraphy*, or the *Artesian Well*, and how many can reply except in the vaguest



SOUTH LONDON RAILWAY—TUNNEL SHIELD.

generalities? Yet it is quite possible to explain these things to any intelligent person without recourse to confusing technicalities or unnecessary elaboration of detail. There must be thousands of persons living in this great workshop of ours who are eager to understand how such things as a *Tunnel*, a *Suspension Bridge*, a *Battleship*, a *Sky-scraper*, or a *Lighthouse* are constructed. This is evident from the interest which is excited by casual articles on such subjects in the pages of newspapers and magazines. If the ordinary reader wishes to inform himself on

matters of engineering interest, he must rely upon occasional and sometimes misleading sources of information, or plunge into professional and costly works which repel and baffle him by their technicalities, their elaborate mathematical demonstrations, and their insistence on minute detail. For the ordinary reader such works are neither readily accessible nor to any great extent valuable. What is wanted is a *cheap and comprehensive work which, in clear and graphic language, aided by every possible pictorial and graphic device, will enable the "man in the street" to grasp the principles underlying the marvellous machinery and constructive apparatus* by means of which the modern engineer has well-nigh transformed the world,

"LONG SOUGHT,
FOUND AT LAST."

THE SPILLWAY OF THE GREAT CROTON DAM.

A MINOR ENGINEERING WONDER.

The removal bodily of a large building from one site to another.

MESSRS. THOMAS NELSON AND SONS are about to publish such a work. It is entitled

"ENGINEERING WONDERS OF THE WORLD,"

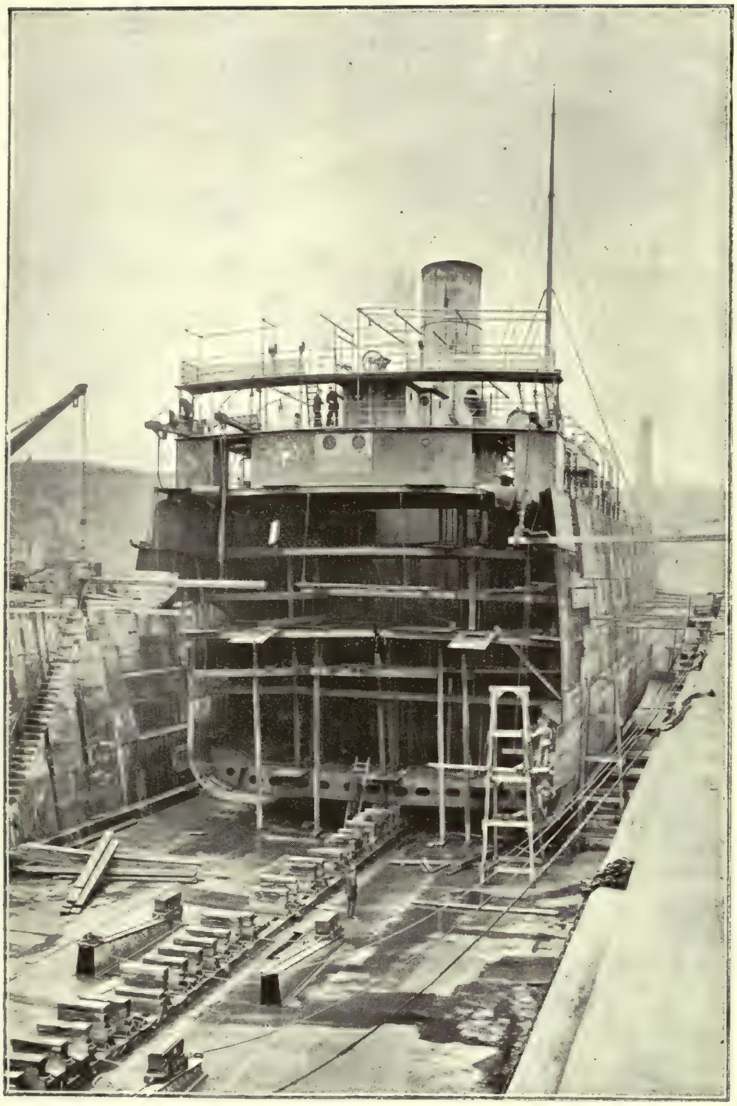
and in every single respect it will satisfy the conditions laid down above. It will tell the story of all those great conquests of mind over matter which have enabled man to well-nigh annihilate time and space, and to harness to his needs the vast forces of nature. It will reveal the mysteries of the elaborate and complicated machinery which is now adapted to every engineering operation. It will prove a

VADE MECUM TO A WHOLE WORLD OF WONDERS,

and it will be written in such a manner as to allure the reader from page to page, both by the intrinsic interest of its subjects and by the lucidity of its descriptions. It will interest and instruct all classes of readers, young and old alike. It will satisfy the *youth's intelligent curiosity*, and enlighten and fascinate the *general reader* by its graphic narratives of such striking feats of engineering as the *salving of the "Gladiator;"* the transport, construction, and work of the *ice-breaking steamer* on Lake Baikal in Central Asia; the *changing of*

ANCHORAGE END, WILLIAMSBURG BRIDGE

the gauge on the Great Western Railway; the *bodily removal of houses* from one site to another, and so forth. On the mechanical side readers will find a clear and pleasant description of the big machinery used in civil, mechanical, and manufacturing undertakings.



THE SALVED PORTION OF STEAMER "MILWAUKEE."

TO WHOM DOES IT APPEAL?

Nor will the *Student of Engineering* and the *Professional Man* find that its pages lack interest, information, guidance, and suggestion. "Engineering Wonders of the World" will enable students and professional men to keep abreast of developments cognate with but outside of their own special activities. The busier an engineer is in his own particular line the smaller is his chance of acquainting himself with what has been done, and what is being done, in other directions. For the professional man "Engineering Wonders of the World" will provide a wealth of information, much of it from the pens of men who have done great things in his profession, and a powerful stimulus to further achievement in his own particular department. It should be specially noted that "Engineering Wonders of the World" *is essentially a modern work.* Only one section, and that a small one, deals with ancient engineering. For the most part the book is devoted to engineering achievements of the last half-century.

THE ILLUSTRATIONS.

A word about the illustrations. Never before has such a comprehensive collection of engineering illustrations and interesting photographs and diagrams been presented in a single book. Even as an album of engineering pictures the book will be most valuable, and well worthy of a place on any reader's shelves. The photographs show great engineering undertakings in every stage of construction, illustrate every aspect of the work, and vivify the text in a remarkable degree. The diagrams have been drawn specially to explain principles without complexity of detail. Thanks to the clearness of the letterpress and to the wealth of illustration, he who runs may read

"ENGINEERING WONDERS OF THE WORLD"

with interest and profit.

BUILDING THE WILLIAMSBURG BRIDGE, NEW YORK CITY.

A SERIAL PUBLICATION.

Recognizing the wide appeal which this work is bound to make, and anticipating a large circulation, the Publishers have decided to issue "Engineering Wonders of the World" in about *twenty fortnightly Parts*, at the modest sum of

Sevenpence net, each Part.

The work will be produced in the high-class manner for which the Publishers are famous. Paper and printing will be of the best, and the volumes when bound will be extremely attractive in appearance as well as handy to consult and peruse. Each Part will contain sixty-four pages of letterpress, scores of interesting and interpretive pictures, diagrams, and HIGH-CLASS COLOURED PLATES. *No such value has previously been offered in a serial issue at 7d. per Part.*

The issue will begin on April 26th, and as the Publishers confidently expect a large demand, intending subscribers should **ORDER NOW.**

NOTE.

PART I.

of

"ENGINEERING WONDERS OF THE WORLD"

is on sale on

April 26th.

PART II.

will be Ready

May 10th.

WORKING 560 FEET FROM THE GROUND.

Synopsis of the Earlier Parts.

This gives an idea of the General Scope of the Work.

PART I.

Ancient Engineering.
White Pass and Yukon Railway.
The Royal Albert Bridge.
The Salving of a Battleship.
The Rotherhithe Tunnel.

PART II.

The Building of the Train-Ferry *"Baikal."*
The Story of the Severn Tunnel.
The Great Zambesi Bridge.
The Conversion of the Gauge of the Great Western Railway Main Line.
A Wonderful Aerial Ropeway in the Andes.

53-TON RANSOMES AND RAPIER'S TITAN CRANE. 67-FOOT RADIUS.

PART III.

The Florida East Coast Railway Extension.
The Bridges of the Menai Straits.
The Manchester Ship Canal.
The Construction of Fishguard Harbour.
The Thames Tunnel.

PART IV.

The African Transcontinental Telegraph.
The Great Victoria Bridge.
Big Gas Engines.
The Tube Railways of London, Part I.
The Suez Canal.

PART V.

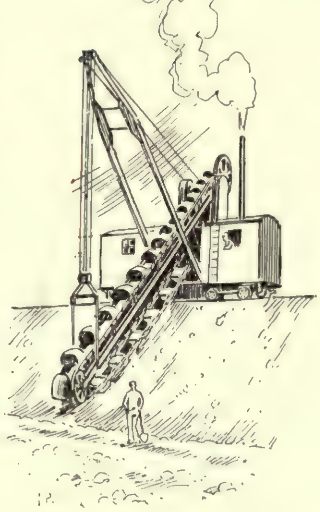
The Canadian Pacific Railway.
Transporter Bridges.
The Tube Railways of London, Part II.
The Development and Designing of Ships.

Each Part contains a Coloured Plate and from sixty to seventy fine Illustrations principally from photographs.


A GREAT WESTERN EXPRESS.


A CALIFORNIAN GANG-PLOUGH DRAWN BY TRACTION ENGINE.

THE SCOPE OF THE WORK.



The following Subjects are included among the Contents:—

AERONAUTICS.

MODERN ARTILLERY.

ENGINEERING.
In Ancient Times.

ARTESIAN WELL.
How Wells are bored.

AQUEDUCTS.
Of England, the United States, Australia (Coolgardie), etc.

BRIDGES.
London, New York, Menai Straits, Niagara Gorge, Victoria Falls, Montreal, St. Louis, Saltash, Forth, Trestle, Transporter, Scherzer Rolling Lift Bridges.

CABLE-LAYING.
The Early Atlantic Cables; Modern Cable-laying Practice.

CABLEWAYS.
In the Andes and elsewhere.

CANALS.
Manchester Ship, Panama, Suez, United States, etc.

DAMS.
Nile, Croton, Marakanave, etc.

DOCKS.
Dry, Wet, and Floating. Their Principles and Construction.

GAS ENGINES.

HARBOUR WORKS.
Dover, Vera Cruz, Fishguard, etc.

IRRIGATION.
In Egypt, India, the United States, etc.

LIGHTHOUSES.

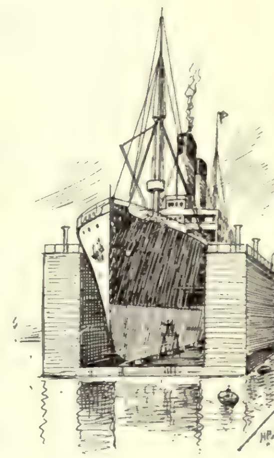
LOCOMOTIVES.

MOTOR VEHICLES.

OIL WELLS AND PIPE LINES.

POWER STATIONS.
At Niagara Falls. In London, etc.

RAILWAYS.
American Transcontinental, Canadian, African, Asian, White Pass, Florida East Coast Extension, Hedjaz, Rack and Mountain Railways, etc.



RAILWAY SIGNALLING.

REINFORCED CONCRETE CONSTRUCTION.

RESERVOIRS. RIVER WORKS AND SHORE PROTECTION.

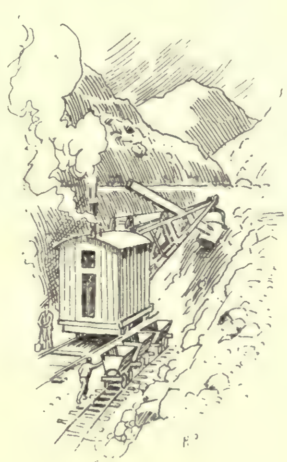
SEWERS. SHIPBUILDING.
The Designing of Ships, Propulsive Machinery, Warships, the Mercantile Marine, etc.

STEEL-FRAME BUILDINGS.

TELEGRAPH LINES.
African and Australian Transcontinental, etc.

TUNNELS.
Alpine, Subaqueous of London, New York, Severn, Tube Railways, New York Subway, Chicago Freight, etc.

WATER SUPPLY to Large Towns. Filter Beds, etc.



Such articles as were not written by practical engineers have been based on thoroughly reliable information, kindly supplied in many cases by professional men whom pressure of business prevented from contributing at first-hand. Every effort has been made to avoid inaccuracies and misstatements.

SPECIMEN PLATE.

A WONDERFUL RAILWAY
ACROSS THE SEA.

Black-and-White reproduction of a Coloured Plate.

Amongst the multitude of CONTRIBUTORS to "ENGINEERING WONDERS OF THE WORLD" the following may be specially mentioned :—

Our Editor, Mr. ARCHIBALD WILLIAMS, B.A.(Oxon.), F.R.G.S., is already well known to a considerable section of the public as the author of many books, among which "The Romance of Modern Invention," "How It Works," "How It is Made," and "Victories of the Engineer" may be selected for special mention. These books have had a large circulation in all English-speaking countries. Though not an engineer by profession, Mr. Williams has always taken a keen interest in the achievements of engineers. This interest developed into a habit of writing simple and easily understood descriptions of mechanical and scientific discoveries and inventions of very modern times. The knowledge gathered during eight years of literary work has now been brought to bear upon the editing of "Engineering Wonders of the World," a task which requires, in addition to a ready pen, a wide acquaintance with what engineers are doing in all parts of the world, and with the methods which engineers employ.

Mr. JOHN J. WEBSTER, Member of the Institution of Civil Engineers, who writes on Transporter Bridges, has had a wide and varied experience as an engineer. The following are among the structures designed by him—the gigantic Wheel at Earl's Court; the Stadium and four of the largest buildings at the Franco-British Exhibition; fixed and movable bridges at Cambridge, Bedford, Northwich, Guildford, Portsmouth, Hull, and a hundred other places; piers for Bangor, Dover, Minehead, Llandudno, Egremont, etc. One of his finest achievements is undoubtedly the Great Transporter Bridge of 1,000 feet span that strides the Mersey and Manchester Ship Canal.

Mr. CHARLES BRIGHT, F.R.S.E., M.I.E.E., is the son of the great cable pioneer, Sir Charles Tilston Bright, and the author of the standard work on Submarine Telegraphy. Mr. Bright is generally acknowledged to be one of the leading experts in that field of engineering, and as such has been associated with the construction, laying, and testing of a large proportion of the cables now flashing their messages along the ocean bed. He took an active part in the All-British Pacific Cable scheme, reporting thereon to the Colonial Office, and in the Cable Communication and Radio-Telegraphic Inquiries.

Mr. HARLEY DALRYMPLE HAY, Member of the Institution of Civil Engineers, has unique qualifications for writing on the Tube Railways of London, which he describes in two very interesting articles. In 1894 he was appointed Resident Engineer in charge of the construction of the Waterloo and City Tube Railway, and subsequently acted in a similar capacity on the Baker Street–Waterloo and Hampstead Tubes until 1902, when he was appointed Chief Engineer for Tube Construction to the Underground Electric Railways Company of London. He has been responsible for the driving of forty miles of single line tubes; is Joint Engineer of the tube authorized under the River Tyne between North and South Shields, and Engineer for the Edgware and Hampstead Railway now before Parliament. It should also be mentioned that Mr. Dalrymple Hay invented the Curve Ranger which bears his name, the hooded-shield-and-clay-pocket system of tunnelling water-bearing strata, and the apparatus used for guiding shields.

Mr. WILLIAM H. BOOTH, M.Am.Soc.C.E., who contributes articles on the Large Gas Engine and Artesian Wells, writes as an expert on these subjects. He has bored wells in practically all the geological formations of the British Isles; and has for years been interested in the development of the internal-combustion engine. It is interesting to note that he made the official test of the first gas engine ever run on blast furnace gas, and advocated, with effect, the possibilities of this type of engine. Mr. Booth has also done railway work in New South Wales, dredging in Holland, and fen drainage in England, and is a specialist in cotton mill machinery.

Mr. A. BEEBY THOMPSON, A.M.I.Mech.E., F.G.S., who writes on the Engineer in the World's Oil Fields, is a consulting engineer and petroleum expert; author of "The Oil Fields of Russia and the Petroleum Industry," "Oil-Field Exploration and Development," etc. Mr. Thompson has personally inspected, supervised, and advised upon oil-field operations in Russia, Roumania, the West Indies, Argentina, Peru, Canada, and West Africa.

Mr. W. NOBLE TWELVETREES, contributor of articles on Steel Buildings, Reinforced Concrete Construction, and Lighthouses, has had many years' experience in the design, construction, and erection of structural steelwork, steam, hydraulic, and electrical machinery. He is the author of "Structural Iron and Steel," "Concrete-Steel," "Concrete-Steel Buildings," "Reinforced Concrete Construction," "Simplified Methods of Calculating Reinforced Concrete Beams," and the inventor of the slide rule which bears his name. Since 1907 he has been President of the Civil and Mechanical Engineers' Society. He is a Life Member of the Manchester University Engineering Society, a Member of the Institution of Mechanical Engineers, an Associate Member of the Institution of Electrical Engineers, and a Member of the Royal Sanitary Institute.

Mr. ALBERT G. HOOD, the writer of the Shipbuilding articles in "Engineering Wonders of the World," is the founder and editor of the *Shipbuilder*, the organ of the great shipbuilding industry, whose readers are to be found in every civilized country on the face of the globe. He is therefore in a position to speak with authority on all matters appertaining to ship construction, and has handled his subject in a manner at once interesting and instructive.

Mr. HOWARD HENSMAN contributes several articles upon Colonial Railways and Telegraphs. Early in life Mr. Hensman came under the magic spell of the late Cecil Rhodes, whose firm friend he became; and ultimately was entrusted with the compilation of the biography of the late South African statesman, a book that had an extraordinary vogue in this country and the United States. It was Mr. Rhodes who led Mr. Hensman to turn his thoughts to the great British Empire beyond the seas, upon which to-day he is an acknowledged authority, there being scarcely a portion of the British Empire with which he has not an intimate acquaintance, a considerable amount of his attention being given to engineering feats and problems.

Mr. STEPHEN PARDOE, whose name appears at the head of the article on the Canadian Pacific Railway, went to Canada at the age of sixteen. There he engaged in many occupations naturally connected with the development of the country—railroading, lumbering, ranching, and agriculture. As a resident for twenty years in that part of the Dominion in which the Canadian Pacific Railway is perhaps the greatest power, and as one who assisted in the actual laying of the track, he is exceptionally well qualified to describe the construction and influence of this wonderful railway.

Mr. JOHN GEORGE LEIGH, author of articles on the Panama Canal, the New York Water Supply, the Niagara Power Stations, etc., is a writer of high standing, whom professional duties and love of travel have frequently taken far afield—to the East, and through the United States, Central America, and the South Pacific. He was one of the first of present-day writers to direct popular attention to the world-wide importance of the Panama Canal enterprise, and to the possibilities of the long-distance transmission of water-generated electricity.

Mr. E. LANCASTER BURNE, Associate Member of the Institution of Civil Engineers and of the Institution of Mechanical Engineers, is a consulting engineer. He has been the manager of a mechanical engineering company, chief draughtsman to a firm manufacturing steam, gas, and oil engines, and assistant engineer to the Westminster Electric Supply Corporation. He is eminently qualified to write the article on the Electric Power Stations of London.

BUILDING THE PYRAMIDS.

GENERAL INTRODUCTION.

By the Editor.

SEVERAL years ago there was staged in London a play which taught the lesson that the man of science, the engineer, the inventor, and the mechanic are classed far too low in the social scale of civilized society; that when human beings are overtaken by circumstances which compel them to fight Nature for a bare subsistence, the man who can devise and make things comes inevitably to the front.

The amenities of modern life are so largely dependent on what the engineer has done for us, that we have some difficulty in appreciating the extent of our indebtedness. Furthermore, the high specialization of professions and callings tends to shut the individual off from a knowledge of the doings of men engaged on work different in nature from his own.

To say that the engineer has benefited mankind more signally than has any other class is hardly to overstate the case. His roads and railways and ships have established easy communication between districts and countries, with all the accruing advantages of a universal commerce. He brings fertilizing water into desert places, and thereby increases the means of human subsistence. His machinery sows and reaps the crops, prepares the grain, and conveys it quickly to the distant market. He is constantly pushing railway tentacles into savage regions and opening them up for civilization; and his

conquests of territory are far more permanent than those of an Alexander or a Bonaparte. The waterfall, once regarded as a mere impediment to navigation, he has turned to account as the producer of motive power for industrial cities. To big centres of population he brings a copious supply of wholesome water; from them he leads, by cunningly devised drains, obnoxious sewage. The machines which he constructs enable us to convert raw material into wealth with a minimum amount of labour, and fill the poor man's house with what, a few decades ago, were the luxuries of the well-to-do. He digs canals and makes harbours and docks for our shipping; spans or burrows under rivers; pierces mountains and fills valleys for the passage of the locomotive. His telegraph and telephone wires reach to the very outposts of civilization.

THE TITLE.

The publication to which these paragraphs are the foreword covers practically the whole field of engineering. The day has long passed when the world's engineering wonders could be reckoned on the ten fingers, or even in three figures. Engineering has advanced rapidly with the correlated sciences, and is now a very complex science indeed. Therefore, in treating of engineering "wonders," our attention must not be confined to descriptions of the most notable feats, though these are dealt with at length. The *principle* is often as wonderful and worthy of notice as the great enterprises to which it has been applied. To make mere magnitude and difficulty of accomplishment the standards of measurement would be to miss the mark in many cases, seeing that the wonders of engineering consist largely of methods devised to avoid difficulties. Nor should we confine ourselves to feats that are visibly imposing. A ferro-concrete building is scarcely an object to wax enthusiastic about, as regards its external appearance; but when the marvellous nature of ferro-concrete construction is grasped, it stands revealed as a wonder of engineering.

This method of treatment increases the educative value of the work as a whole. It may at times afford the reader some slight mental exercise, but will surely result in his taking a deeper interest in what the engineer has done and is doing. A large part, be it noted, of the letterpress is from the pens of professional engineers, whose status is sufficient guarantee for the worth of their respective

contributions. The balance is based upon first-rate information, much of it supplied by experts whom pressure of business prevented from contributing at first-hand. Our debt to these gentlemen we here acknowledge gratefully.

In length, the articles vary considerably, according to the nature of the subject. They are short where brevity suffices; long where the subject demands a more or less detailed explanation.

THE SCOPE OF THESE VOLUMES.

As the title implies, the whole world is laid under contribution for our material, selected on its own merits. English and Continental railways, for instance, receive little notice, being overshadowed by the more imposing, romantic, and extensive systems of America, Asia, and Africa. For mountain tunnels we go to the Alps; for canals to Panama, Suez, and the United States; a notable cableway is found in the Andes; the chief aqueducts noticed are in Australia, the United States, and England. And so on.

Some articles, such as those on shipbuilding and power signalling, are quite general in their application. Room has been made for descriptions of unique feats like the transportation of the parts of the train-ferry *Baikal* to Central Asia. Here and there we bring to notice subjects about which little is generally known—for example, the underpinning of large buildings. Nor has the mechanical side of engineering been neglected: our list of contents includes, among other mechanical items, the steam and electric locomotive and their new rival, the aeroplane. We have seen to it that the reader should have no reason to complain about lack of variety and comprehensiveness.

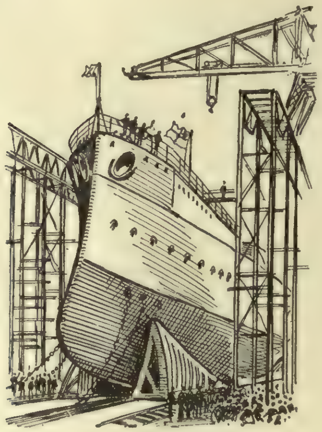
Except in the first chapter, attention is confined almost entirely to engineering practice after the year 1800. A back limit had to be set somewhere, and this date is convenient, as the development of the steam engine and the many forms of engineering stimulated thereby belong to the nineteenth century. We may add that but few articles deal with work done prior to 1850, and these exceptions are justified by the character of the enterprises described. The Menai Straits and Saltash Bridges and the Thames Tunnel—to mention three—are worthy to rank with the greatest engineering feats of the present day, as any subsequent eclipse in point of size is compensated by the exceptional difficulties attending their construction.

ARRANGEMENT OF SUBJECTS.

A word as to the arrangement of the articles. From the point of view of mere symmetry a grouping of subjects, each having its items set in chronological order, was advisable. On the other hand, the general reader would undoubtedly prefer a frequent change of topic; so, out of consideration for him, grouping has been sacrificed in favour of a general distribution of subjects. This course made it necessary to supply an exhaustive index, in which the facts scattered over the work are brought together in due order.

OUR ILLUSTRATIONS.

A large proportion—roughly two-fifths—of the total page space is devoted to illustrations. These fall under two main heads—the pictorial, to show the progress of work; the diagrammatic, to demonstrate a principle, a function which diagrams perform more effectively than mere verbal explanation. We have added a number of sketches—such as those giving a bird's-eye view of the Manchester Ship and Panama Canals and the London Tube Railways—which present a subject in a manner not attainable by a photograph, a map, or a diagram. The photographic cuts are based upon originals selected carefully, and we trust that the reader will concur with our opinion that as a collection they are thoroughly representative.



ANCIENT ENGINEERING.

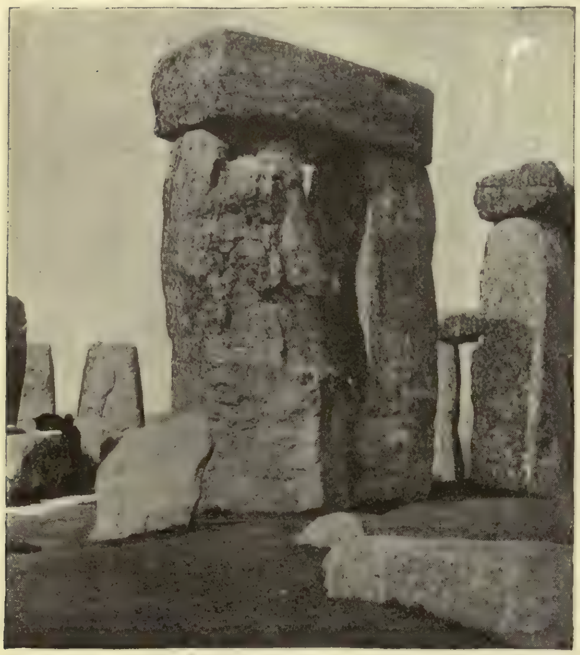
BY THE EDITOR.

IT has been well said that a characteristic of modern thought is the increasing desire to look backwards, and appreciate the work of generations which have long passed away, thereby checking any inordinate pride that might be bred by a self-satisfied concentration on the immense advance made, during the last few decades, in all branches of science.

In the absence of contemporaneous detailed accounts of an ancient nation's manner of life and civilization, we are obliged to base our estimates of its social and scientific status largely upon those works of its engineers which, in a more or less ruined condition, have survived the ravages of time. Even where we have the testimony of ancient but more recent writers to help us, their information is of double value when corroborated by the discoveries of energetic excavators, who perpetually bring to light fresh reasons for admiring the extent to which, in the historical infancy of the human race, mind triumphed over matter. Thousands of years ago men were busy erecting splendid monuments and constructing works of the utmost importance to the physical well-being of their fellows. Then the tide of conquest rose in Central Asia and swept westwards, destroying man and his monuments alike; and for many hundreds of years the engineer's activities were confined, with few exceptions, to the construction of huge castles and religious edifices.

The Engineer a Great Historian.

With the revival of learning, greater political stability, the invention of gunpowder, and the rediscovery—for as such it must be regarded—of many principles of natural physics, engineering awoke from its long sleep, and now we have to our hands such mechanical appliances as the ancients could hardly even have dreamed of—appliances in themselves as wonderful as the results for which they are partly responsible. Yet, considering the difficulties which even the modern engineer encounters, notwithstanding these appliances, the work performed by men who had at their command little else than a bountiful supply of cheap labour and, as is likely, comparative freedom from galling contracts, may well make us think highly of those great ones of old whose engineering achieve-



STONEHENGE.

One of the enormous trilithons. The comparative size may be judged of by the human figures in background.

ments have perpetuated the memory of empires long passed away.

In order to treat so large a subject as the present in the limits of a few pages, it is necessary to confine our attention to a few typical examples under each branch of engineering.

Arguments in favour of the habitation of Mars by rational beings are founded on the so-called "canals" that score the surface of the planet. Some authorities uphold that they have an *order* which could not have resulted from mere chance.

Stonehenge.

Similarly with the mysterious monuments at Stonehenge and Carnac. The huge stones of which these are composed impress one chiefly by their size, which in turn suggests the problem of how they were transported and erected. At Stonehenge still stand erect huge stones weighing individually many tons, while a number of their fellows lie prostrate around them. We

THE "TABLE OF THE MERCHANTS." *Photo, L. le Rouzic, Carnac.*

A huge Dolmen at Carnac in Brittany. The horizontal stone is 18 feet long and 10 feet wide, and rests on the top of large upright slabs. A Dolmen is the central chamber of what was once a burial-ground.

have here evidence of an ordered arrangement and no little skill in handling large masses of stone at a period that must date back to far before the Roman Conquest.

At Carnac, in Brittany, are perhaps the most wonderful of all the monuments of the prehistoric Stone Age. There one may indulge to the full the emotions aroused by gazing on monuments of, in many cases, unknown origin. The stones may be classified under two headings—the *dolmens*, or tombstones; and the *menhirs*, or single pillars. There are more than two hundred dolmens in the district, all built on the same plan—several large upright stones capped by a huge slab. Originally they formed the central chambers of burial mounds. The action of wind and water, and the robbing of the earth by agriculturists for use on their fields, have gradually denuded them. The capstone of one tomb measures 28 feet by 14 feet, and is several feet thick; another, 16 feet by 16 feet—both of a size to do honour to the noble dead whose bones once lay beneath them.

The Stones of Carnac.

THE GIANT OF KERDEF. *Photo, L. le Rouzic, Carnac.*

A solitary stone pillar or Menhir, 17 feet high.

Even more striking than these erections are the menhirs. On the top of the tomb of some prehistoric Achilles lie the fragments of a rough granite pillar, which, when upright, rose 67 feet into the air. Its weight has been estimated at over 350 tons. We are able to give an illustration of another monster, "the Giant of Kerdef."

The Carnac "Lines."

The "Lines" of Carnac are unique. They are to Brittany what the Pyramids are to Egypt, or the Taj-Mahal to India. Dolmens and solitary monoliths seem but side-shows in comparison. For a distance of about two and a half miles stretch eleven more or less parallel rows of huge up-ended stones, three thousand or so in number. The largest must weigh upwards of 40 tons, and the sum total of the whole "Lines" cannot fall short of 12,000 tons. There is evidence to show that these phalanxes of granite were transported and erected at least three thousand five hundred years ago by men quite ignorant of the use of iron. They represent a great engineering feat, and

that is about all that can be said concerning them.

As movers of huge masses of stone, the ancient Egyptians may claim first place. The huge scale of their monuments and temples is largely responsible for having preserved them from the fury of the flood of destruction that again and again has swept through the valley of the Nile. Some of the most notable objects to be seen in Egypt are the mighty statues erected in honour of her kings. The twin colossi of Amenhotep III., which have sat for many centuries outside Thebes, overlooking the desert, were hewn out of single masses of granite brought hundreds of miles down the Nile from Assuan. Each colossus is about 53 feet high, and weighs several hundreds of tons. Even more striking is the fallen statue of Rameses II., lying in the Theban temple named after him, the Rameseum. It was cut from a red granite monolith, 60 feet high, and its weight has been computed by Sir J. Gardner Wilkinson at 887 tons 5½ cwt. This block also undoubtedly came from the Assuan quarries. We may wonder what force it was that overthrew so gigantic a monument, as there are no signs of Egypt having been visited by an earthquake.

Egyptian Colossi.

The remains of an even larger colossus were discovered by Mr. Flinders Petrie at Tanis. The mere chips that he found weigh several tons each; and from them he has reckoned the avoirdupois of the complete statue at 1,200 tons; its height, with pedestal, at 125 feet. "The effect," wrote Mr. Petrie, "when there were no high mounds here, must have been astounding. The temple was probably not more than 50 feet high, and the

A Veritable Monster.

THE "LINES"

These rows of huge stones extend for about 2½ miles. Individual

tallest Tanis obelisks were less than 50 feet high. The statue must therefore have towered some 65 feet above all its surroundings, and have been visible for many miles across the plain."

Then there are the Pyramids, those marvellous aggregations of massive stones which still rank among the world's chief wonders. The Great Pyramid has a base 764 feet square, and originally rose 480 feet into the air—exceeding the height of St. Paul's Cathedral, London, by 120 feet; that of the Capitol at Washington by nearly 200 feet. The weight of this mass, some 6,840,000 tons, renders it the greatest of all stone-built erections. Professor Rawlinson has made the interesting calculation that its material would build a city containing twenty-two thousand houses such as are found in an ordinary London square; or, if cut into one-foot cubes, would reach for nearly 17,000 miles—a distance equal to about two-thirds of the earth's circumference at the Equator.

The Great Pyramid of Egypt.

This Pyramid is remarkable for more than its mere size. Many of the stones which it includes must weigh between 40 and 60 tons. The granite blocks roofing over the central sepulchral chamber are nearly 19 feet long, from 3 to 4 feet deep, and 2 feet broad; and, moreover, these stones are fitted together with the nicest care, besides showing in their arrangement a full understanding of the necessity for constructing an arch-shaped roof to withstand the pressure of the huge superincumbent mass. Then again, in the building of the Pyramids it was not merely a question of hauling stones to the site; they had in some cases to be elevated nearly 500 feet above the base.

AT CARNAC. *Photo, L. le Rouzic, Carnac.*

stones weigh upwards of 40 tons. Their purpose is unknown.

The Great Stones of Baalbec.

Among the wonderful ruins of the Temple of the Sun, at Baalbec in Syria, may be seen the largest squared stones ever used for a building. In one of the walls, at a height of 19 feet above the level of the ground, are three monster blocks, all over 63 feet long, and 13 feet high. Their width is unknown. In a quarry near Baalbec lies another stone, hewn, but not yet separated entirely from the rock. This mammoth, shown in our illustration, is 69 feet long, 14 feet thick, and 17 feet high! Its weight has been estimated at 1,500 tons. We cannot doubt that the hewers meant to incorporate it into the temple. Dr. W. M. Thomson, author of *The Land and the Book*, who visited the ruins, was impressed not more by the mere size of the stones in the wall than by the perfection of their finish. "The corresponding surfaces of these enormous stones are squared so truly," he writes, "and polished so smoothly that the *fit* is exact. I was at first entirely deceived, and measured two as one, making it more than 120 feet long. The *joint* had to be searched for, and, when found, I could not thrust the blade of my knife between the stones. What architect," he asks, "of our day could cut and bring together with greater success gigantic blocks of marble more than 60 feet long and 12 feet square?" In the quarries from which these colossal stones came can be seen to-day partly separated blocks already grooved for the insertion of wooden wedges, which, when saturated with water, would tear

THE COLOSSI OF AMENHOTEP III. AT THEBES. *Photo, J. P. Sebah.*

Each colossus is 53 feet high, weighs several hundred tons, and is cut out of a single granite block brought from the distant quarries of Assuan. That on the right is known as the Statue of Memnon.

them from their native rock. The wetted wedge was the ancient substitute for modern explosives.

How did the ancients manage to transport and raise such masses of stone? A generally definite answer cannot be given, though we may make some "guesses at truth" which should not be far wide of the mark. On an old Assyrian sculpture in the British Museum is the representation of a large number of slaves dragging a sledge on which reclines a massive stone bull. In front are men laying down wooden rollers, while others urge the sledge behind with levers. A somewhat similar proof of ancient methods is given by an Egyptian painting of a colossus drawn on a sledge by one hundred and seventy-two men, ranged in four rows of forty-three each. In one respect ancient and modern expedients were alike. An individual stands on the leg of the image, and claps his hands as a signal to the team of men to pull together. When a single piece of granite, weighing 1,200 tons, which formed the pedestal of the equestrian statue of Peter the Great at St. Petersburg, was drawn to its site, a drummer was placed on the top of the huge block to perform the same service.*

How did the Ancients move Great Weights?

THE GREAT STONE OF BAALBEC.

It is 69 feet long, 17 feet high, and 14 feet wide. Estimated weight, 1,500 tons. The man reclining on this stone affords a standard of size. It is probably the largest cut stone in the world.

The great Temple of Diana, built at Ephesus

* *Quarterly Review*, ccxl., 430.

THE FALLEN STATUE OF RAMESES II.

in the Rameseum, Thebes. The weight of this monster has been calculated at 887 tons $5\frac{1}{2}$ cwt. How the monolith from which it was carved was transported to Thebes is a mystery.

NEAR VIEW OF THE STEPPED PYRAMID AT SAKKARA, EGPYT.

LOOKING UP THE GREAT PYRAMID.

This photograph gives some idea of the size of the stones used, though those shown are far from being the largest in the Pyramid.

VIEW OF THE SECOND PYRAMID

from the top of the Great Pyramid. Shows part of the smooth facing with which the Pyramids were originally coated.

THE GREAT PYRAMID. *Photo, J. P. Sebah.*

The greatest mass of stone ever raised by man. It has a base 764 feet square, is 464 feet high, and weighs about 7,000,000 tons. Herodotus tells us its erection occupied 100,000 men for twenty years.

about 600 B.C., had 127 columns, each 60 feet high and 7 feet in diameter, shaped from single blocks of marble. The architects, Chersiphron and his son Metagenes, moved these great masses eight miles from the quarries to the temple site by enclosing them in wooden frames and rolling them across country with the help of oxen.

A Suggestion.

Given sufficient brute force, a mass weighing hundreds of tons could be moved horizontally without much difficulty. But the up-ending of a huge colossus or obelisk or menhir needed the use of more advanced mechanical principles. How did the old Britons raise one of the Stonehenge monoliths? Perhaps they built an inclined ramp of hard-beaten earth to the site of the stone, hauled it up this over rollers, and tipped it down the end into a hole prepared for it. Or they may have adopted the method employed till comparatively recent times in India, of gradually prying up the top end of the stone with levers and ramming earth beneath it until the stone was sufficiently upright to be pulled into its final position with cords. To get a horizontal impost on the top of its two upright supports, the latter were probably surrounded with a mound of earth up which the impost was hauled. Having served its purpose, the earth would then be removed.

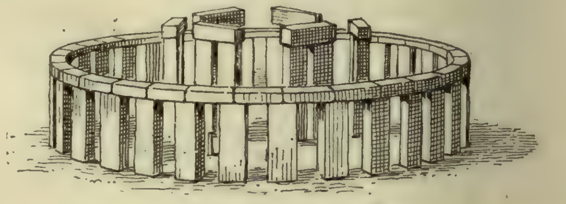
Herodotus tells us that an inclined road of polished stone was constructed from the banks of the Nile to the site of the Great Pyramid—about three-quarters of a mile—for transporting the blocks brought down the Nile from

ASSYRIAN WORKMEN HAULING A STONE BULL.
(From a bas-relief in the British Museum.)

the "Arabian Mountain." He also mentions that ten years were spent in making this road, which, in his opinion, was a hardly less notable work than the building of the Pyramid itself. As to the manner of raising the stones to their places in the structure, opinion is divided between the lever and the inclined plane. Herodotus' account of the building is as follows: "This pyramid was built in the form of steps.......When they had first built it—that is, the base—in this manner, they raised the remaining stones by machines made of short pieces of wood, having lifted them from the ground to the first range of steps. When the stone arrived there it was put on another machine that stood ready on the first range, and from this it was drawn to the second range on another machine, for the machines were equal in number to the ranges of steps; or they removed the machine, which was only wood, and portable, to each range in succession, whenever they wished to raise the stone higher; for I should relate it in both ways, as it is related. The highest parts of it, therefore, were first finished [as regards the smooth casing], and afterwards they completed the parts next following; but last of all they finished the parts on the ground, and that were lowest." This description, on which is based the first of our coloured plates, is quite understandable, and seems to render unnecessary the theory of a huge inclined ramp of earth and sand, extending from the Nile to the Pyramid, raised gradually to keep pace with the growing height of the stonework. The construction and demolition of a ramp 480 feet high, most of a mile in length, and having a base breadth sufficient to give the necessary "angle of stability" for the sides, would have been an enterprise far more arduous than the actual building of the Pyramid, which, according to Herodotus, occupied 100,000 men for twenty years. It is not a great assumption to suppose that men who were able to embark enormous stones on barges, float them down the Nile, and land them again, possessed the tackle needed for raising them up the successive steps of the Pyramids.

Herodotus on the Building of the Pyramids.

Was an Inclined Plane used?



STONEHENGE
as it probably appeared originally.

Turning to engineering feats of an essentially useful character, we may instance the canal dug about 1450 B.C. to connect the Nile with the Red Sea. A much greater, but less authentic, work was the deflection of the Nile by means of a dam near Memphis in 5000 B.C.—"a work of appalling magnitude," as it has been described. The ancient Chaldeans were skilled irrigators, who intersected their country with numerous canals from 20 to 30 feet wide and several feet deep. During an expedition in 330 B.C.

Useful Engineering Feats.

THE SPHINX.

A rock carved into the shape of a recumbent woman-headed lion. The largest sculpture in the world.

down the Tigris towards India, the ships of Alexander the Great were hindered by a dam that had been thrown across the river. There is plenty of evidence to show that from the earliest times the inhabitants of the Nile and Euphrates valleys were well acquainted with the science of irrigation.

The public engineering works carried out by the Romans are in many ways marvellous. At a very early date in its history Rome was provided with at least one great *cloaca*, or sewer, and others were added as the need arose. These main sewers were very solidly built of large stones weighing upwards of 3 tons, and portions of them remain in good condition to this day.

Roman Sewers.

The aqueducts which supplied Rome and some of the greatest cities of her Empire with water are, even in their present ruinous condition, sufficient proof that their builders were great engineers. "The least observant visitor to Rome is awed and impressed by the ruins of the aqueducts......When he comes to inquire a little more closely into the history of these wonderful structures, he finds not only that the ignorance of scientific principles to which it was once the fashion to attribute their origin did not exist, not only that the popes of later days have succeeded in restoring a few of them so as to make them practically useful in quenching the thirst of the modern Roman, but also that the aqueducts have a curious and interesting history of their own which admirably illustrates the life and progress of the great Republic. As her fortunes mounted, so the arches rose higher and

Roman Aqueducts.

THE WONDERFUL ROMAN AQUEDUCT AT SEGOVIA IN SPAIN.

It has 109 arches, some of which are 100 feet high. The length of the arch portion is about half a mile.

higher. As her dominion extended, so these mighty filaments stretched farther and farther up into the hills. Like a hand upon the clock-face of the Empire was the ever-rising level of the water supply of Rome." *

Facts about the Aqueducts.

The first of the aqueducts of Rome was built by the great Censor Appius in the year 312 B.C., and was named after him the Aqua Appia. It led water 7 miles from the hills to the poorer quarters of the capital. Forty years later came the Anio Vetus, 43 miles long, from above Tivoli. The Aqua Marcia, completed in 144 B.C., had a course of 61 miles, and cost the equivalent of about £1,600,000. It delivered water at the level of the lofty Capitol. Other notable aqueducts built subsequently were the Claudia and the Anio Novus (28–50 A.D.), 58 and 46 miles long respectively; and the Trajana (109 A.D.), 42 miles. The last of these has been restored.

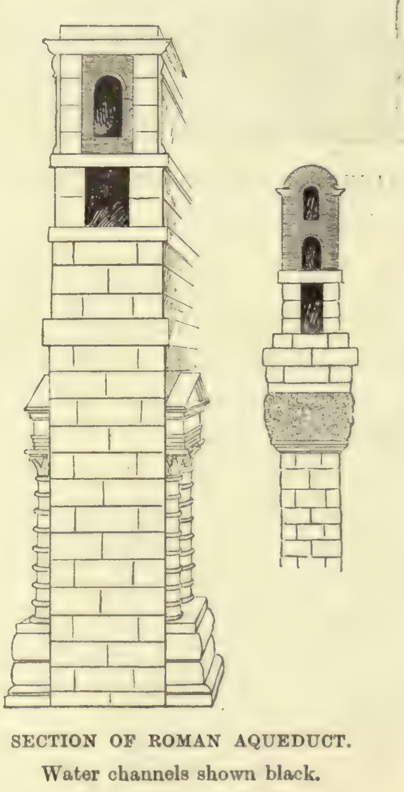
Astonishing Figures.

These aqueducts, large and small, had a total length of 346 miles, and, in order to follow a hydraulic gradient without pressure, they were carried over arches—some of great height—for 44 miles. It has been calculated that in the days of the Empire the quantity of water poured by them daily into Rome was about 350,000,000 gallons, or about one and a half times the supply of Greater London! Assuming the maximum population of Rome to have been 1,500,000—and this is probably a generous estimate—every inhabitant would have an allowance of well over 200 gallons per day.

The water, on reaching the city, was stored in reservoirs, whence it flowed through a network of leaden pipes to all parts. One may see in the British Museum a specimen of the stop-cocks which the Romans used. The abundant supply accounts for the number of fountains and of public baths, some of which could accommodate two or three thousand persons at a time; also for the artificial lakes in the amphitheatres, on which small naval engagements were fought to amuse the mob.

Roman Hydraulic Science.

Though, as a rule, a Roman aqueduct was an artificial stream running on a uniform gradient from source to point of delivery, the Romans had acquaintance with the employment of the high-pressure main. Vitruvius mentions the "siphon" for negotiating a valley, and recommends the staunching of joints by means of fine ashes mixed with water; also the need for filling a siphon slowly and using air vents. Lead pipe siphons 18 inches in diameter and 1 inch thick have been found at Lyons; and as long ago as 115 B.C. a pipe siphon backed with concrete was built at Alatri, in Italy, to withstand a "head" of 340 feet of water.



SECTION OF ROMAN AQUEDUCT.
Water channels shown black.

Roman roads were of the same high quality as the Roman aqueducts. This great military nation realized that successful conquest required

* Dr. Thomas Hodgkin, *The Walls, Gates, and Aqueducts of Rome.*

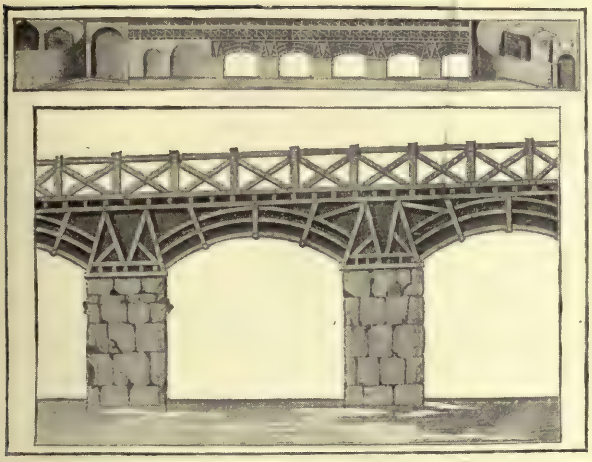
THE PONT DU GARD AQUEDUCT, NEAR NISMES, FRANCE.

The greatest height is 180 feet. Length along second tier of arches, 885 feet. The lowest arches are of 51, 63, and 80½ feet span respectively.

good means of communication, and whithersoever its armies penetrated the roads went with them. Even in Britain, the "Ultima Thule" of Latin poets, we have many examples of the skill of the Roman roadmaker, whose work was not equalled by his successors for many centuries, and is hardly to be surpassed by the product of the stone-breaking mill and steam-roller. We may criticise the uncompromising directness that characterizes the course of a Roman road—a directness that apparently scorned to turn aside to avoid a heavy gradient—but when we analyse the "metalling" of the highway, we can admire only. For the best class of road the engineer dug a shallow trench, 3 feet or so deep and 18 feet wide. The bottom he beat hard, and covered with large flat stones. On these he placed a layer of small stones; on them again a course of concrete; and finished the work with a surface of accurately jointed flat stones, sloping gently from the centre to the edges of the road to throw off the water. He also provided a kerb on either side, and a broad footpath for pedestrians. So well was his road made that in many cases it survived the neglect of the Dark Ages, and we could name localities where it still serves its purpose.

Roman Roads.

As builders of walls the Romans had nothing to learn. They knew the secret of a mortar even harder and more tenacious than the stones it held together. Their bridges, too,



A ROMAN ARCH BRIDGE ACROSS THE DANUBE.
(From Arch of Trajan.)

were solidly and scientifically built, arches of 120 feet span being not unknown.

A branch of engineering in which the ancients showed considerable skill was that of tunnelling. King Hezekiah, who reigned in Jerusalem about 700 B.C., "fortified his city by leading water into it, and he bored through the rocks with bronze and dammed the water into a pool." * The boring referred to is probably the Shiloah Tunnel, some 580 yards long, in which has been discovered an inscription setting forth that the boring was conducted from both ends simultaneously — a statement curiously confirmed by the fact that the tool marks on the walls in the two halves run in opposite directions. The breadth of the tunnel varies from 2 to 3 feet, its height from 6 to 10 feet. The engineers managed to maintain a correct level, but were somewhat astray in the horizontal alignment.

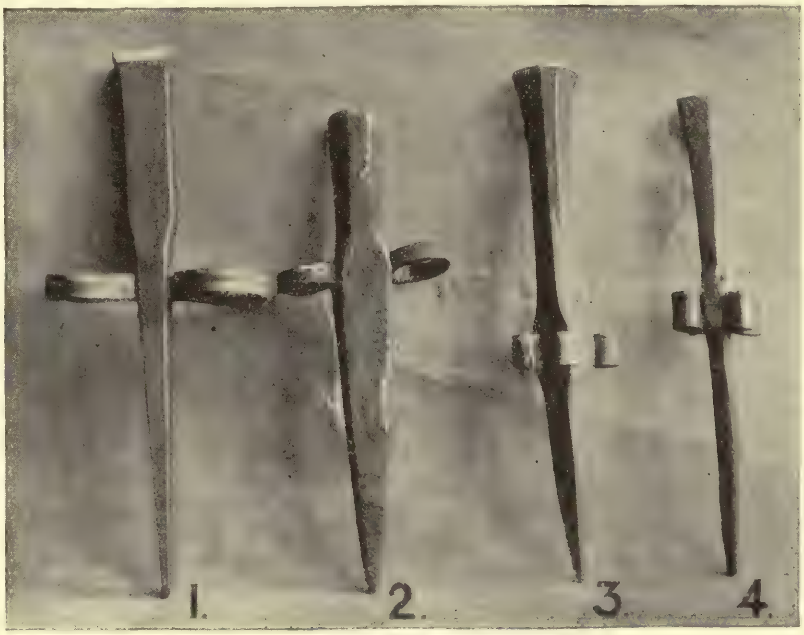
A Jewish Tunnel.

* Sirach.

Coming a little nearer the present day, we find the Greek Eupalus driving, in 625 B.C., a tunnel 8 feet square and nearly a mile long to bring water into Athens. The so-called Grotto of Posilippo, near Naples, is an old Roman road tunnel 2,316 feet long, 22 feet wide, and 89 feet high on the average—surely a notable tunnelling feat! Yet it was a mere bagatelle to the making of a drainage tunnel, at the order of the Emperor Claudius, to empty Lake Fucinus into the Liris. This tunnel was 3 miles long, and for thousands of feet penetrated hard carnelian that had to be chipped away painfully with the chisel.

Great Roman Tunnels.

Reviewing the work done, we may wonder what tools the workers used. It remains a mystery how the Egyptians hewed, squared, and carved their granite pillars and colossi.



An interesting instance of ideas perpetuating themselves. The instruments shown are "stakes," or field anvils, used for straightening the edge of a scythe or sickle. Nos. 1 and 3 are such as are manufactured to-day at Birmingham. Nos. 2 and 4 are of Roman make, dating from about 300 A.D. Observe the exact reproduction of the rings in the respective types.

Photo, V. White and Co., Reading.

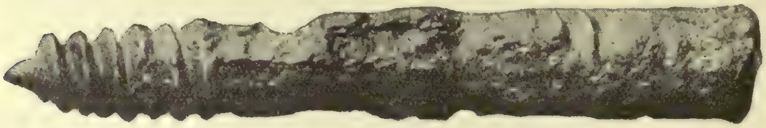
The Tools of the Ancients.

Very few traces of iron have been discovered among their monuments, yet it is difficult to imagine that any other metal would have served to shape so hard a material as granite. How did the old Britons cut the tenons and mortises for the great trilithons of Stonehenge? The Romans had their "levels," "plumb-lines," and "measuring-rods"—Vitruvius tells us that much—and archæologists have brought to light things which prove the Roman workshop to have been better provided than many of us might think. The cases of the British Museum contain samples of carpenter's augers and centrebits of a very modern character; also metal squares, and, what we should little expect, a very efficient pair of proportional compasses. At Silchester have been exhumed the remains of iron planes very similar to those which now hail from the land of the Stars and Stripes. Such a thing as a metal screw we should hardly look for among a collection of Roman curios; yet we are able to give an illustration of such a screw, which actually has a point that proves the idea embodied in the famous Nettlefold patent to have been known in these islands fifteen hundred years ago.

A Roman Metal Screw.

So, putting one thing with another, we may conclude that, so far as manual tools, as distinct from machines, are concerned, the ancients were fairly well provided, while of their skill their works are sufficient witness. This chapter may close suitably with some words of Dr. J. Elfrith Watkins: "If the demands of what we are pleased to call our higher civilization were to exhaust our mines of coal, our wells of oil and gas, and our beds of ore, so that steam and iron should no longer be the slaves of man, could a modern engineer erect so magnificent an edifice as Karnak, bore so wonderful a tunnel as the Grotto of Posilippo, or construct such a satisfactory system of water supply as Rome enjoyed during the Augustan age?"

Conclusion.



A ROMAN GIMLET-POINTED SCREW.

Photo, V. White and Co., Reading.

Date about 300 A.D.; found at Silchester. The discovery of this screw proves that the Romans were skilled mechanics.

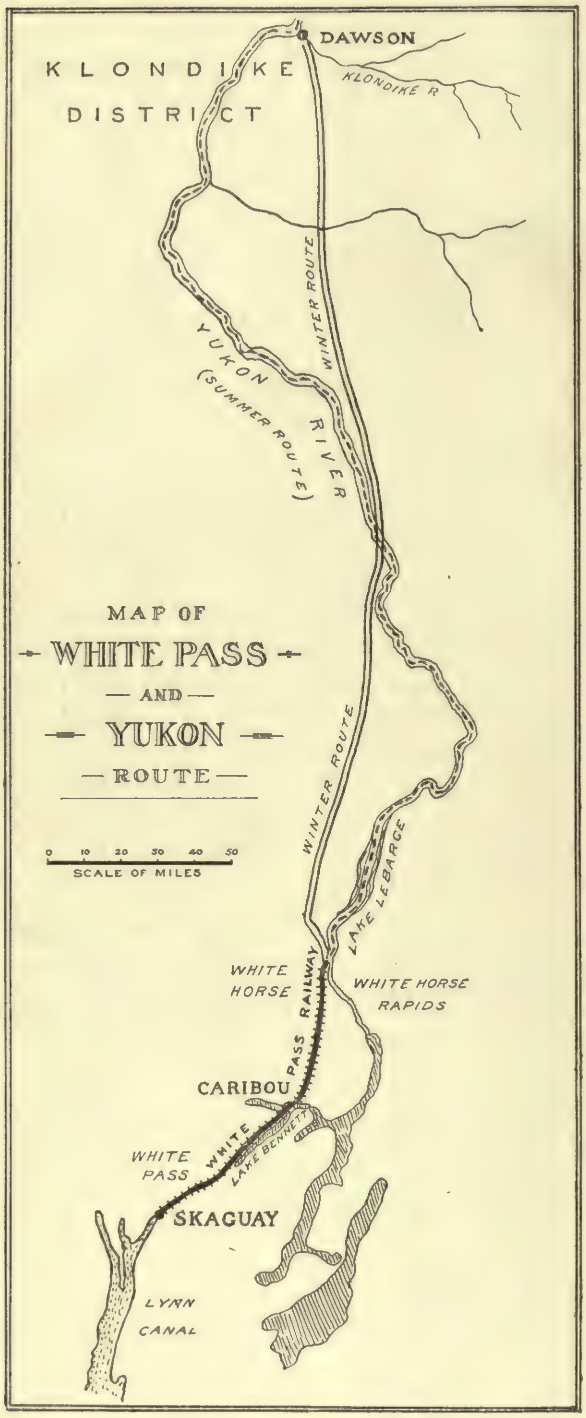
A RAILWAY OF THE FAR NORTH.

The White Pass and Yukon Railway.

The building of this railway is one of the most interesting chapters in the history of the now famous Yukon goldfields. The following description is from the pen of one who has been prominently associated with the railway since its inception.

TOWARDS the close of the summer of 1896 some miners prospecting along the Yukon River discovered the golden riches of the Klondike. The credit for this discovery has been claimed by two different parties, but the fact is that the discovery seems to have been substantially simultaneous on two different creeks flowing into the Klondike River. The first discoverers kept their discoveries to themselves as far as possible; but rumour soon extended up and down the Yukon River, and other miners arrived rapidly from the various mining camps scattered for thousands of miles along its banks, so that when the spring of 1897 came, and mining operations were once more possible, there was already a considerable population prospecting and mining in the Klondike. As the summer of 1897 advanced, some of these men began sending out their gold dust, which they had till then kept stored in flour-sacks and empty meat and vegetable tins on the floors of their cabins or tents. The wealth of the ground which had been opened up so far exceeded all their previous mining experiences, that these men honestly believed that if they held their gold dust until the following year the world would be so flooded with it that, in their own words, "there would be no price for it." Consequently, just as a farmer hurries his wheat to market when he anticipates a decline in price, these men were anxious to get their gold dust to San Francisco or Seattle before gold lost its value in the markets of the world by reason of the anticipated flood from the Klondike. The first Klondike gold, amounting to $1,000,000 (£200,000), arrived in Seattle in August 1897, and the accounts of the won-

Discovery of Gold on the Yukon River.



The heavy dotted line indicates the river route from White Horse to Dawson, used during the summer.

derful riches of the Klondike which accompanied the gold immediately caught the attention of the world, and gave rise to a rush for the Klondike from almost every civilized portion of the globe, which continued for upwards of a year. In this race the people living nearest to the Klondike, of course, had the advantage, so that a number of Americans and Canadians were able to find their way there before the winter set in, and consequently were on the ground in the spring of 1898, before navigation opened and made it possible for others to get in.

Rush for the Klondike.

In the rush for the Klondike three routes were chiefly used. The first was by the mouth of the Yukon at St. Michaels, which had hitherto been the only route used. The second was from the head of a fiord of the North Pacific known as the Lynn Canal, across the coast range of mountains to the headwaters of the Yukon River, and thence down-stream to the Klondike. The third, which at the time was widely advertised, was known as the overland route from a station called Edmonton on the Canadian Pacific Railway; and a number of people attempted this route, though few succeeded in getting in by it. The all-water route *via* the mouth of the river was by far the easiest of these routes, in addition to being the only one theretofore used; but, on the other hand, it was practicable during a few summer months only, and involved a slow voyage up-stream;

Difficulties of Travel.

and when once the rush set in there was a good deal of uncertainty as to whether or not the goldseekers could find accommodation on the few and comparatively small steamers at that time in service on the Lower River. For this reason, and because of the great advantage in getting quickly to the Klondike, the large majority of the goldseekers preferred to run the risks of crossing the coast range from the head of the Lynn Canal, either through the White Pass or the Chilcoot Pass to Lake Bennett on the Upper Yukon, and drifting down the rapid waters of

the Yukon River to the Klondike in small boats built by themselves on the banks of the Yukon. After navigation had closed in the autumn of 1897 the goldseekers still continued to arrive throughout the winter, and being unable to get over the passes till the spring, had to remain at the head of Lynn Canal, where they settled down on a gravel flat called by the Indians Skagua, which has since become known to the world as Skaguay.

a company of soldiers, while the Canadians kept a few mounted policemen there, who were only allowed by the United States the status of private individuals, as the disputed territory was *de facto* in the possession of the United States. But there were no laws of the United States applicable to it, and no courts established to give effect to them if there had been any. In these circumstances Skaguay became a sort of Tom Tiddler's ground and centre of

CLEARING A PATH FOR THE RAILWAY THROUGH A PINE FOREST.

Exciting Times at Skaguay.

The Klondike rush made this place of great importance, and a hot dispute at once arose between Canada and the United States as to whether the true boundary between these countries placed Skaguay in the United States or in Canada. This point was not settled in favour of the United States until years afterwards by international arbitration. Meanwhile the United States Government occupied Skaguay with attraction for all the lawless and criminal characters who are invariably attracted by the opening of a new mining district, but who seldom find such favourable opportunities for carrying out their lawless methods as were afforded in Skaguay in the early days. These people were led by a man named Smith, better known as "Soapy Smith," and had things pretty much their own way in Skaguay until the better element rallied round the railway builders, and inaugurated an era of self-govern-

PERILOUS WORK.

On the steep mountain sides a foothold was obtained by chaining logs to iron bars drilled into the rock.

ment in July 1898 by electing a Vigilance Committee and killing "Soapy Smith."

The gravel flat upon which Skaguay was situated was hemmed in by snowclad mountains on three sides, and by the sea on the other. The trail which connected it with the interior followed the rocky banks of the Skaguay River for some distance through the mountains, and then, turning sharply to the left, ascended the canyon of the White Pass to the Summit. Beyond the Summit it was necessary to climb still higher on the precipitous sides of Turtle Mountain in order to avoid the many arms of what is now known as Octopus Lake. From Turtle Mountain the trail descended to Log Cabin, and thence to the head of Lake Bennett. Although it was called a trail, it is not what most people understand by that term in the sense of being a path at all suited for reasonable travel by man or beast. Before the discovery of the Klondike it had been the line adopted by the Indians in their migrations from the coast to the upper waters of the Yukon; and when the Klondike rush began, the Indians piloted the goldseekers over this line and assisted them to carry on their backs their personal belongings, for which they made a charge averaging about two to three shillings per pound weight. The early goldseekers having abused the confidence of the Indians by liquidating their indebtedness in patent medicine advertisements and other alleged paper currency of no value, the Indians thereafter exacted silver dollars, and would accept nothing else for their services. They were good climbers, and, like all Indians, too lazy and improvident to make any attempt to improve their trail. They had never seen a horse, and considered that any rocks, boulders, or fallen timber which a man could climb over, and any swamps or streams which he could wade, were no objection whatever in a line of travel from one place to another. As the goldseekers came in increasing numbers they began to bring pack-horses with them, and the owners of the first horses were compelled to do a certain

The White Pass Trail.

minimum amount of work in order to make the Indian trail at all possible for horses. But the moment that a horse could by any means be got over the trail, all further improvement ceased, and was never again resumed. The first horses were got over when there was no great crowd, and it was possible to unload a horse and lead him light over a bad place, reloading him on the far side. But as the rush increased this could no longer be done, and it was then that the trail became so fatal to horses as to earn the sinister title of the "Dead Horse Trail." The chief reason why the trail was so fatal to horses was because the owners were mostly ignorant, and began by overloading them at Skaguay, and trusted to luck for their horses being able to forage for themselves, not knowing that the mountains were so steep that a horse could not move to either side of the trail, and that every blade of scanty grass within reach had long since been eaten. During the rush this narrow trail was blocked, so that neither man nor horse could go faster or slower than the speed of the huge living serpent that slowly wound its way over the pass. When a delay occurred, the horses for miles back had to stand loaded, as no one could tell at what moment travel would be resumed. In this way the horses became exhausted under their loads long before they had reached the Summit, and frequently fell and broke their legs on the rough rocks, in which case the load was removed and travel resumed across the dead body of the horse. In one of the worst places on the trail *there were over* 3,500 *dead horses in a distance of a mile!*

Sufferings of Baggage Animals.

In order to put an end to the terrors of the trip across the coast range of mountains from Skaguay, and also to afford commercial access to the interior of the country, the White Pass and Yukon Railway was projected from Skaguay to the head of navigable waters on the Yukon River, whence access is obtained to the interior of the Yukon Territory and Alaska by many thousands of miles of rivers and lakes.

A Railway projected.

Though the length of this railway is only 115 miles, it extends through no fewer than three different jurisdictions, and is subject to as many different sets of laws—namely, those of the United States, of the Dominion of Canada, and of the Province of British Columbia. The first 20 miles, from the sea at Skaguay to the Summit of the White Pass, is through United States territory; from the Summit to the shores of Lake Bennett the line is in the Province of British Columbia; and thence to White Horse it is in the Yukon Territory of Canada, and subject to the Federal authority of the Dominion of Canada. When construction was first commenced, in 1898, the situation was further complicated by the dispute between Canada and the United States as to the ownership of the territory between the Summit of the White Pass and the sea at Skaguay.

Construction was commenced in 1898, while the Klondike rush was at its height, which, of course, greatly increased the difficulty of securing and keeping an adequate supply of labour. War between the United States and Spain having broken out that spring, most of the available shipping on the Pacific coast had been chartered by the United States Government, and this enhanced the difficulty of providing transport for the men and the material, which had to be carried 1,000 miles from the bases of supply on the Pacific coast to the ocean terminus of the proposed railway at Skaguay. At that time there was no telegraphic communication, and this increased the difficulties entailed in working 1,000 miles from any base of supply.

The Railway commenced.

When the railway surveyors reached Skaguay on May 27, 1898, they found the town site

in the possession of some 10,000 squatters, who had no titles themselves other than possession, but nevertheless demanded prohibitory terms for the right-of-way from the sea inland across the gravel flat which constituted the town site, and considerable difficulty was experienced in arranging this matter before construction could commence.

Legal Difficulties.

The line of the trail not being adapted for railway purposes, no less than five preliminary surveys were made in order to determine the best available line to the Summit. The mountain-sides being precipitous and thickly timbered with small scrub spruce to the timber line, and polished smooth above the timber line by the action of glaciers, the work of surveying was difficult. But within a few weeks the line was definitely "located" for construction, and was made up of portions of each of the five preliminary surveys.

While making the surveys, and subsequently during the work of construction, the railway builders were brought into close relations with the bears who were the original inhabitants of the mountain-sides along which the line ran. Prompted by curiosity and hunger, the bears used to investigate the camps of the railwaymen, and soon became so cunning and expert that nothing edible was safe from them unless it was watched night and day. The continuous heavy blasting at first frightened the bears, but they soon learnt how to shelter themselves from the falling rocks and stones. They also learnt to recognize the warning shouts of

Tame and Intelligent Bears.

PLACING A BLASTING CHARGE.

the foreman, and to post themselves so as to take advantage of the temporary absence of the men in order to steal the contents of their dinner-pails. At some of the camps the bears became so tame that they would eat out of the men's hands, and would even stand to be photographed.

ROCK WORK ON A SLOPE.

In the foreground is seen a rough bridge giving access to the ledge.

Actual construction commenced in June 1898, and trains were running by August 25 over the first 14 miles of the line. The working force had increased to nearly 2,000 men on August 8, when the news of the gold discoveries at Atlin reached the construction camps and reduced the numbers to under 700 in two days. It was October before the working strength could be restored, by which time the work was almost entirely above the timber line, and exposed to the full force of the Arctic winter storms. In many places the men had to be "roped" while working, in order to prevent them being blown off the steep mountain-sides, where the granite was so smooth and slippery that the only foothold was often obtained from logs chained to iron bars drilled into the rock. The cold and the action of the wind was so intense that the men had to be relieved every hour, as longer exposure numbed not merely their bodies but their minds, so that they had not sense enough left to tie a knot securely, or do other simple things of similar nature. Throughout the winter the thermometer ranged from 20° to 40° below zero, and sometimes even lower, at the construction camps. Nevertheless the work was pushed continuously, and on February 18, 1899, the first train reached the Summit of the White Pass, 2,865 feet above the sea-level, and 20 miles distant from Skaguay.

Labour Troubles.

Working under Difficulties.

After the Summit had been reached, the working force was transferred to the comparative shelter of the timber at the Bennett end of the line for the remainder of the winter, as there was no special object in continuing to expose the men above timber line on work which could be done more easily when spring

GRADING THE TRACK.

should come. Meanwhile communication between rail-head at the Summit and the construction camps beyond was maintained by means of an iced roadway, which was constructed at a sufficient elevation above the surrounding snowfields to be kept clear of snowdrifts by the constant action of the wind. The traffic soon ground down this roadway into one of the most perfect highways imaginable for either fast or heavy sleighing. In addition to construction material and camp supplies, an immense passenger and freight business was carried over it during the spring of 1899. Amongst other things carried were the boilers, engines, and woodwork for a fleet of steamers built at Lake Bennett that spring, so that when the railway reached the lake and navigation opened, there was "a fleet in being" ready to carry the traffic down the Yukon River to the Klondike. The largest single piece carried over the iced road was a 30-ton boiler built in England for use in the Klondike. This was brought to the Summit of the White Pass in the spring of 1899 over the new railway track, and taken by twenty horses over the iced road to Lake Bennett, whence it was floated on a barge down the Yukon, including the passage of the dreaded White Horse Rapids, and in due course arrived safely in Dawson.

The Sleigh Trail.

As the spring advanced, the iced road was kept up with increasing difficulty, till finally even light traffic by night became impossible. A channel was then blasted for six miles through the thick rotten ice on Summit Lake, and connection was thus established with the new railway grade beyond the lake, which thereafter was used as a roadway till the rails were laid and trains could run over it.

As soon as the iced road became useless, such numbers of the public insisted on using

the construction trains for the conveyance of themselves and their goods that there was danger of a serious accident, and it therefore became necessary to attempt some sort of a public train service over the unfinished line, though this interfered greatly with the movements of the construction trains and with the work of the construction gangs. Nevertheless, the first train reached Lake Bennett on July 6, 1899, and 40 miles of railway through the mountains connected the navigable waters of the Pacific with those of the Yukon.

Overworked Trains.

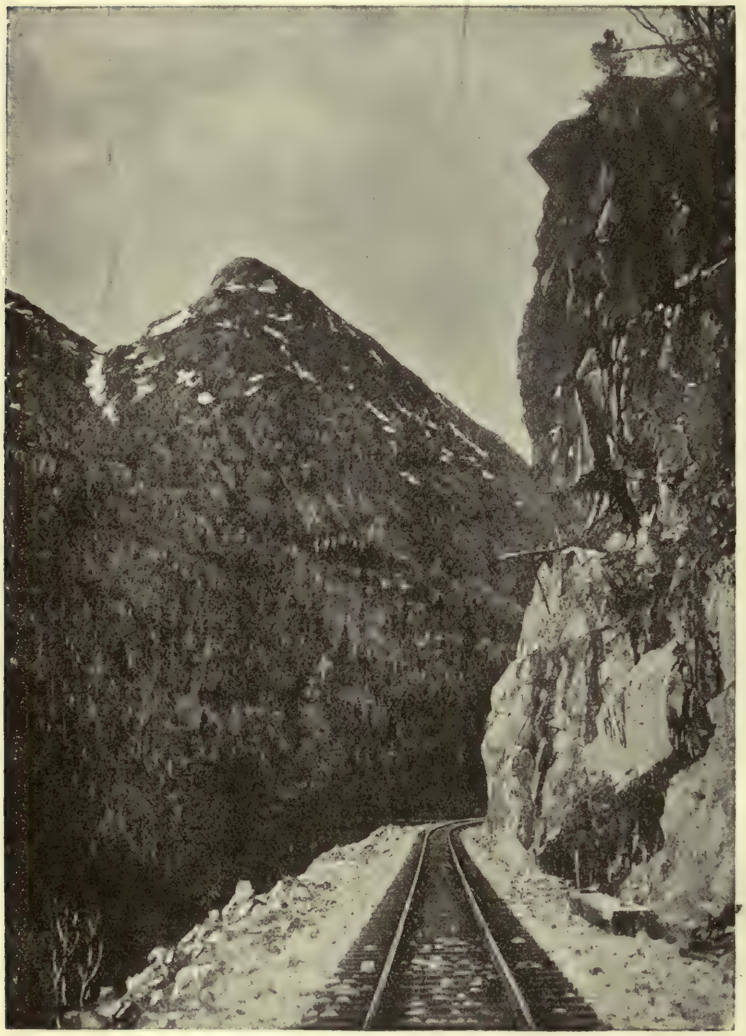
The nature of the work between Skaguay and Lake Bennett added immensely to the difficulty of construction during an Arctic winter. After leaving the gravel flat at Skaguay, the line follows rocky mountain-sides deeply serrated by fissures and canyons, and in many places so steep and inaccessible that the men had to be suspended by ropes while establishing working platforms. From the fourth to the twenty-eighth mile the road bed had to be blasted out of the solid granite mountain-sides, except where bridges occurred, and every ton of ballast had to be hauled from the gravel flat at Skaguay, as there was no loose gravel or soil available for ballasting on the rocky sides of the mountains. A 500-foot tunnel on the sixteenth mile, high up on the slippery side of Tunnel Mountain, was inaccessible from the grade line, being cut off by a deep canyon, which was not bridged till after the tunnel was completed; and meanwhile the powder, steam-drills, fuel, and water required for work on the tunnel had to be carried on men's backs up the steep mountain by a zigzag trail cut in the precipitous granite for that purpose. Snow to a depth of from 25 to 30 feet had to be removed from the more exposed portions of the line, and even in sheltered places the snow was from 6 to 7 feet deep. Upwards of 500,000 cubic yards of snow and ice had to be removed in clearing the line for work. Sixty-seven bridges, aggregating 11,540 feet, had to be built, many of them over deep, inaccessible canyons. Taking the engineering and climatic difficulties into account, a year was a remarkably short time in which to complete the 40 miles of line through the mountains from Skaguay to Lake Bennett.

Difficult Engineering.

From this lake there is a continuous waterway down the Yukon River to its mouth at St. Michaels, nearly 2,500 miles distant, and by means of the sundry lakes and tributary rivers there is water communication with practically the whole of the interior of the Yukon Territory and Alaska. But this waterway is only available for comparatively small boats bound down-stream, as neither Miles Canyon nor the adjacent White Horse Rapids are navigable by boats of any considerable size, and the rapids are too swift to admit of any boat that has once gone down them being got back again, even with ropes and steam capstans. Hence for all commercial purposes the head of navigation on the Yukon commences at the foot of White Horse Rapids, and it was necessary to extend the railway to that point, a distance of 75 miles from Lake Bennett.

The Waterway of the Yukon River.

Work was accordingly at once commenced on this line. The line along the shore of the lake for 27 miles involved a great deal of heavy rock work, upon which progress would be slow, so it was decided to establish camps for the rock gangs only along this part of the line, and to transfer the remainder of the working force to the foot of Lake Bennett, and put them to work between Caribou Crossing and White Horse Rapids. If this latter portion of some 45 miles could be completed by the time navigation opened in 1900, the lake would form a connecting link between the two pieces of railway until the gap could be closed by completing the railway along the



A NASTY CORNER AT PORCUPINE POINT.

shores of the lake. In order to carry out this programme successfully, it was necessary before navigation closed in 1899 to assemble at Caribou Crossing at the foot of Lake Bennett a supply of rails, sleepers, construction plant, and material, in addition to rolling stock and camp supplies, sufficient for nine months' work and the construction of 45 miles of railway. Once navigation closed on Lake Bennett the work beyond would be cut off from rail-head until the lake was again free from ice in the following June. The steamers already mentioned as having been built on Lake Bennett in 1899 were fully occupied in the Klondike traffic; but the railway folk built hastily steam-barges of large size, and with their aid were able to accomplish the task of getting everything to Caribou Crossing before the ice closed navigation in the autumn of 1899.

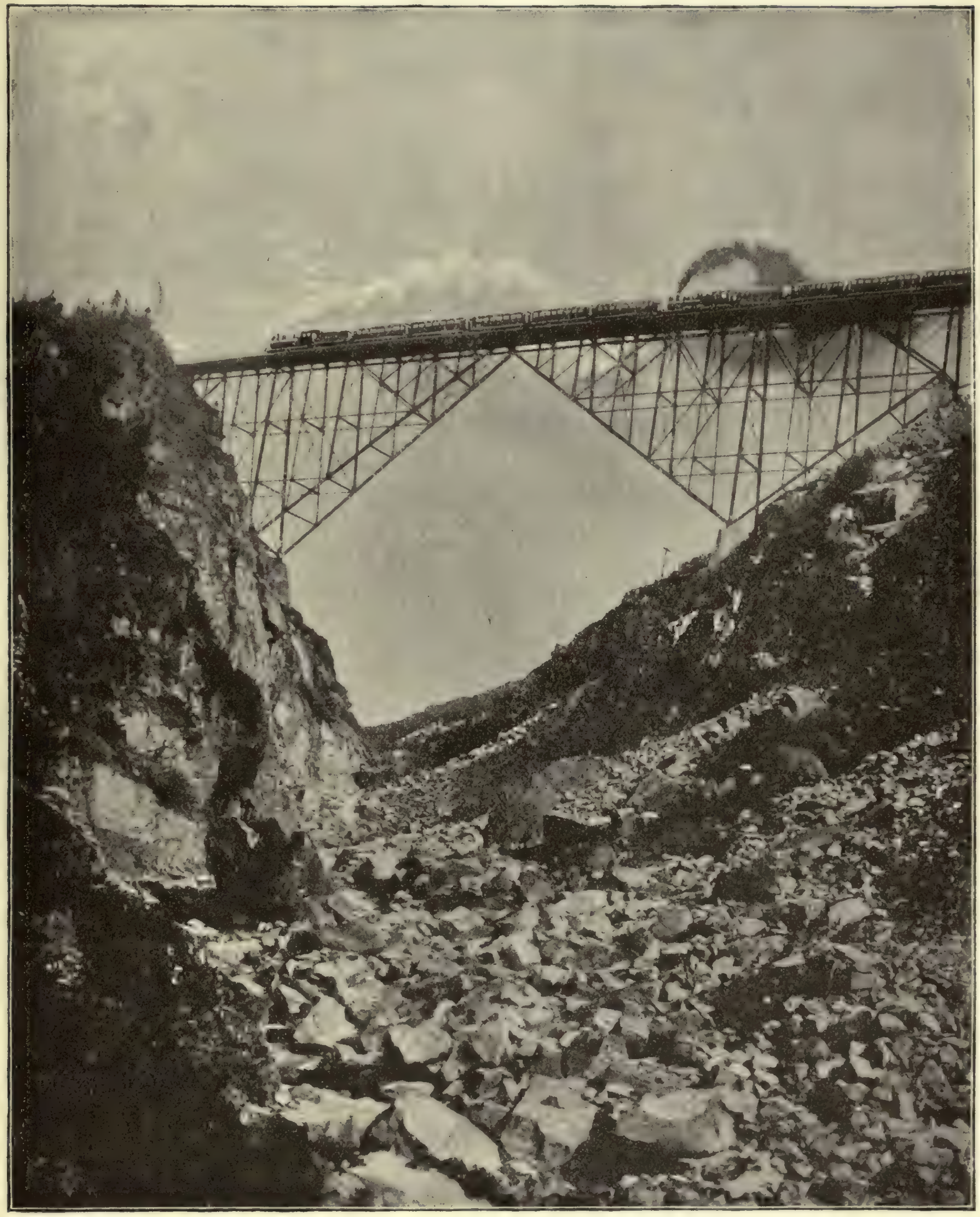
Preparations for the Winter.

Work was pushed on vigorously throughout the winter, but great difficulty was experienced by reason of the ground being frozen, not merely for a few feet below the surface by the winter frost, but to a great depth by the glacial cold of prehistoric ages. The frozen earth proved to be more difficult to deal with than solid rock, since, having no cleavage lines, it was tough in addition to being as hard as rock. When the spring came, cuttings made in this frozen earth began to thaw and run, and embankments made with the frozen material began to melt and settle down, and soon the surface of some of them was 5 or 6 feet below the grade line. All this involved constant refinishing of the line, and a great deal of extra work; notwithstanding, the first train ran from Caribou Crossing into the new town of White Horse on June 8, 1900.

Trouble caused by Frozen Earth.

By that time the ice had melted on Lake Bennett, and navigation was open, so that by means of the steamers on the lake through communication was at once established between Skaguay and the foot of the White Horse Rapids.

During the winter and spring work had been progressing steadily along the rocky



THE LARGE CANTILEVER BRIDGE OVER SWITCHBACK CANYON.

It is 835¾ feet long, and carries the track 267 feet above the bottom of the canyon.
Observe the disposition of the locomotives.

A ROTARY SNOW-PLOUGH AT REST.

The line is worked all the year round, and sometimes drifts 35 feet deep have to be cleared for considerable distances.

shores of Lake Bennett, where the heaviest work consisted of blasting a road bed round or through the numerous steep, rocky capes which jutted out into the deep water of the lake. These capes were separated from each other by little bays, at the head of which the water was for the most part shallow, so that the material taken from the rock cuttings on the capes was used in some places for building embankments across the shallows, thus avoiding curvature of the line as much as possible.

Progress beside Lake Bennett.

By the end of July 1900 the 27 miles of line along the shore of the lake were completed, and the last spike was driven on July 29, thus closing the gap between the two ends of the railway. It is a curious fact that the first train over the completed line was south bound—that is, going out from White Horse to Skaguay—and was composed of empty cars, which had been working on the north end of the line, but which were, of course, sent to Skaguay to be loaded as soon as the gap in the railway was closed.

The general characteristics of the railway are as follows. It has a gauge of 3 feet, and is laid with 56-lb. steel rails with 24-inch spliced bar fish-joints, and on curves, etc., with tie-plates and rail-braces. The sleepers or "ties" are $6' \times 8'' \times 6\frac{1}{2}''$, laid 2,816 to the mile. The road bed in excavation is 10 feet wide, with a 2-foot ditch at each side, making the standard width in excavation 14 feet at the base. On embankments the finished width at top is 12 feet. Earth side slopes in excavation are 1 to 1, and on embankments $1\frac{1}{2}$ to 1. In loose rock excavation the slopes vary from $\frac{1}{2}$ to 1 to 1 to 1, according to circumstances; and in solid rock the side slopes are $\frac{1}{4}$ to 1.

Description of the Railway.

The maximum gradient between Skaguay and the Summit is 3·9 per cent., and the maximum rise in any one mile is 201 feet, the theoretical grade being equalized for curvature — that is, reduced on curves to compensate for the loss by friction, and to maintain a uniform load on the engine. This maximum grade scheme is uniformly maintained, except at sidings, from the fourth mile-post to

Gradients.

the Summit, a distance of 16 miles. Beyond the Summit the gradients are much easier and comparatively short, the maximum being 2·91 per cent. and the average ·84 per cent. against south-bound traffic.

Bridges.

The more important bridges are of steel, of varying styles of construction to suit the local conditions. The largest is a steel cantilever bridge across a deep canyon near the Summit. This bridge is 835·9 feet long, and the track is 267 feet above the bottom of the canyon. The minor bridges are of wooden trestle construction with 12″ × 12″ posts, and spans between trestles of $15\frac{3}{4}$ feet.

Alignment.

The alignment is based on a maximum curve of 16°—that is, a radius of 359·3 feet. There are forty-four such curves between Skaguay and the Summit, and twelve between the Summit and Bennett. The total deflection or curvature between Skaguay and the Summit is 4,392°, equalling 12·2 circles in the 20 miles. Between the Summit and Bennett the corresponding figures are total deflection 2,689°, equalling $7\frac{1}{2}$ circles. The longest straight length between Skaguay and the Summit is 2,831 feet in the fourth mile, and the longest curve is 1,095 feet in the fifteenth mile. The outer rail on curves is elevated for a speed of 15 miles an hour between Skaguay and the Summit, and of 25 miles an hour between the Summit and Bennett. Beyond Bennett the engineering presents no special features.

The elevation of the track above sea-level at the Summit of the White Pass is 2,865 feet, and at the Summit at Log Cabin 2,916 feet, and at Lake Bennett 2,158 feet.

A telegraph and also a telephone line are used in connection with the railway working, and these are also available for public service.

The line is worked continuously throughout the year, though the winter storms on the White Pass sometimes last for weeks with temperatures far below zero. Snowdrifts as high as 35 feet have at times to be cleared away for considerable distances, and the normal depth of the drifts dealt with daily by the rotary snow-ploughs in keeping the track clear averages from 3 to 5 feet.

NOTE. — *The photographs illustrating this article were kindly supplied by the White Pass and Yukon Railway Company.*

A ROTARY SNOW-PLOUGH AT WORK.

Photo, Great Western Railway Company.

THE ROYAL ALBERT BRIDGE AT SALTASH.

BY FELIX J. C. POLE.

This bridge was one of the gigantic experiments made by Isambard Kingdom Brunel, and its successful erection illustrates the resourcefulness of that gifted engineer.

AMONGST the earlier and largest types of iron structures the Royal Albert Bridge, which spans at Saltash the river Tamar (at that point a magnificent expanse of water 1,100 feet wide and about 70 feet deep), occupies a very prominent place. It was designed and erected by the great engineer, Isambard Kingdom Brunel, and forms the connecting link by which railway communication was first established between the counties of Devon and Cornwall. The railway history of the latter county is repleté with engineering achievements, as evidenced by the numerous lofty, massive viaducts spanning its well-wooded valleys; but these sink almost into insignificance in comparison with the huge structure at Saltash, which is at once the last and greatest of Brunel's railway works. The outstanding features are its large dimensions, coupled with the economical character of the design and the form of superstructure; while the method by which the foundations of the piers were secured and the girders erected was unique.

As early in the last century as 1844 a railway into Cornwall was proposed, but a line was not constructed till many years after that date. One of the chief reasons for this delay was the necessity of bridging the river Tamar; for although the expedient of a steam-ferry to carry the trains over it was at one time proposed, a bridge appeared essential. Several designs were prepared, and some of them were objected to by the Admiralty on the ground of possible obstruction to the all-important naval base at Devonport, adjoining the site of the bridge; but ultimately, in 1852, a scheme was adopted for a structure crossing the river in two main spans, a single pier in the bed of the river offering the least possible interference with the waterway. This involved the construction and erection of two immense girders, or trusses, as they are sometimes termed, having their ends connected by chains from which the railway was to be suspended.

The Need for a Bridge across the Tamar.

ISAMBARD KINGDOM BRUNEL,
the Designer and Engineer of the Bridge.
(*Rischgitz Collection.*)

It is our desire in describing engineering works to avoid the use of statistics as much as possible, but in the case of large bridges figures are essential to a due appreciation of the magnitude of the work. The Royal Albert Bridge has a total length of 2,200 feet. The two main spans over the river are each 455 feet, and the side spans, seventeen in all, are from 70 feet to 90 feet. The height of the centre pier from its foundation to the top is 240 feet, and the railway is 110 feet above the level of high-water.

Facts and Figures.

Like many other engineering marvels, the part most difficult of accomplishment, and, from an engineering point of view, by far the most interesting, is out of sight, and probably little appreciated by those who cross the bridge. Thus one of the chief difficulties was the building of the pier in the centre of the river. Indeed, the task at Saltash was even greater than in the case of the celebrated Britannia Bridge spanning the Menai Straits, where a rock rose above the surface of the water. No such natural facility was afforded in the course of the river Tamar. A depth of 87 feet 6 inches below the water had to be dealt with, and mud and rock débris removed until good foundations were secured. To effect this a specially constructed watertight cylinder, 95 feet long and 35 feet in diameter, was employed. About 20 feet above the end destined to be lowered into the water a dome was provided, converting it into a diving-bell; and, lest this should prove unmanageable in deep water, an inner gallery or jacket, 4 feet wide and 20 feet high, was formed round the inner circumference of the cylinder below the dome. This in turn was divided into eleven compartments, into which, by a pneumatic apparatus, air could be

The Foundations of the Bridge.

pumped to expel the water, and enable work to be carried on without having to employ compressed air in the entire space under the dome.

The great cylinder was constructed on the river-bank and floated into position, being finally sunk into the river-bed in June 1854.

Sinking the Cylinder.

Delay in penetrating the mud was caused by an oyster-bed, which had to be cut through by one edge of the cylinder. It had been ascertained that the surface of the rock dipped to the south-west to the extent of about 6 feet in the width of the pier, and the cylinder bottom was therefore made oblique so as to correspond; but even when the rock was reached some irregularities of the surface caused the cylinder to tilt considerably from a vertical position, making necessary the use of the pneumatic apparatus to gain access to the rock and excavate in it a suitable resting-place for the cylinder. By February 1855, however, the latter had been sunk to its full depth, and then rested on solid rock; but much trouble was caused by a spring of water issuing from a fissure in the rock, which had to be stopped with timber piles. This done, a ring of masonry was built, the mud enclosed removed by suction, and the space built up. Finally, towards the end of the year 1856, the masonry was completed to the cap of the pier, situated about 12 feet out of the water, and the upper part of the cylinder was unbolted and taken ashore, thus completing the difficult initial task.

Meanwhile arrangements had been progressing for providing the ironwork for the centre spans that were to form a striking and by no means inharmonious feature in the landscape. Each of the two main girders was formed of a

A GIRDER BEING ERECTED BESIDE THE RIVER. *By permission of Mr. T. H. Quick.*

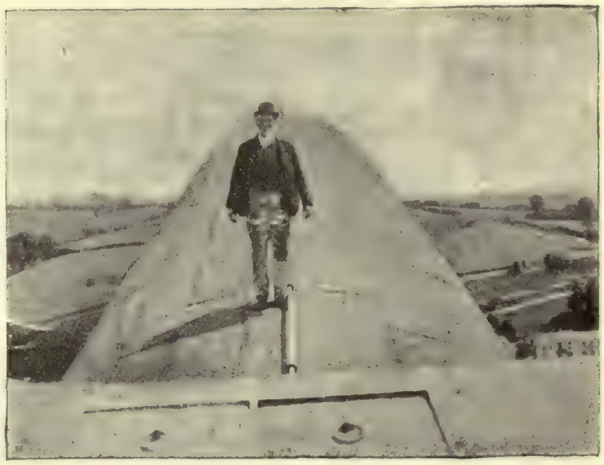
curved wrought-iron elliptical tube 16 feet 9 inches broad and 12 feet 3 inches high, constituting a flat arch, while massive chains were suspended from end to end on either side of the tube. At eleven points in the length of the girder the chains were connected to the tube by upright standards, from which in turn the ironwork on which the track was to rest took its support. This arrangement was especially noteworthy as combining the tubular and chain suspension principles, with the result that the entire structure is elegant and substantial in appearance, while the cost was reduced to a minimum—a feature very necessary to suit the finances of the Cornwall Railway Company, its builders.

The Ironwork of the Main Spans.

The ironwork was erected on the Devonshire shore of the river; and when the first span had been completed, elaborate arrangements were made for floating it into position. To do this it was necessary that it should be transferred securely to pontoons, but it was essential that these should be brought to the girder, which was too massive to be embarked in any other way. Accordingly, space for the admission of water was excavated underneath the girder near the ends, and in each of these "docks" two iron pontoons were placed. The latter drew about 8 feet 6 inches of water, and were capable of sustaining a weight of 500 tons each, or a total of 2,000 tons, as compared with the 1,100 tons weight of the ironwork. By means of valves, water was admitted into the pontoons, and they sank on to timbers placed to receive them. Upon each pair of pontoons was erected an elaborate timber framework to support the weight of half the girder. It consisted of stout timber props, some of them 40 feet long, extending upward to the arched tube, and attached to it by iron suspension rods, so that when the operation of floating was completed the pontoons would be free to pass away from under the girder.

Scheme for Floating the Spans.

Every part having been tested, extensive preparations were made for moving the pon-



This view gives an idea of the size of the arched tubes.

toons and their precious load. On this part of the work about five hundred men were employed. Five vessels, obtained from the Government authorities, were moored in different positions in the river—one on the eastern side, another in the centre, a third on the western side above the bridge, while the other two occupied intermediate positions. On board were a number of men from the dockyard and sailors to operate the powerful capstans for warping the tube into position. Four hawsers were also attached to windlasses at different points on shore, thus completing the arrangement for guiding and controlling the pontoons in every direction as they floated out from the shore. Able nautical assistance was also obtained; while to ensure that his instructions should be clearly understood and immediately complied with, Brunel appointed to each of the vessels one of his assistants as "captain," whose duty it was to superintend the men and execute his orders. Signals were given from a platform in the centre of the girder, near which Brunel stationed himself.

Preparations made.

A MAIN GIRDER BEING RAISED INTO POSITION. *Photo, Great Western Railway Company.*

Indeed, so complete were the arrangements that, to prevent the attention of a captain being diverted from his supervisory duties by looking out for signals, he was allotted a lieutenant whose sole function was to watch for signals, acknowledge them, and pass the message to his chief. The signals, which had to be acted on simultaneously at the different vessels, were made by red and white flags held in front of black boards, which were turned towards the vessel signalled to, and all signals were carefully rehearsed.

The Launch.

September 1, 1857, was the day decided upon for the operation, and tens of thousands of people assembled to witness the launching of the mass of ironwork which was to form the Cornish half of the bridge. Precisely at the appointed hour the pontoons were unmoored, capstans and guide ropes were set to work, and the unique craft commenced to move. Immediately a tremendous cheer was raised by the crowd on the Devonshire shore, and responded to with equal heartiness by spectators on the opposite bank. Then ensued an almost breathless silence as first one rope, then another, exerted pressure on the pontoons, in accordance with the signals of the engineer. Slowly and surely the structure was drawn into position and carefully adjusted. Water was admitted into the pontoons, and as the tide fell they were allowed to drift away, leaving the girder resting on the piers, the under side of the ironwork to carry the railway being only a few feet above the water.

The occasion was celebrated locally as a

general holiday, and it is estimated that from thirty to forty thousand visitors journeyed to Saltash. No vessel was allowed to approach the piers while the pontoons were being navigated into position, but below the point at which a notice board announced this regulation the river was alive with yachts containing pleasure-parties, and innumerable boats were also in evidence. In the town of Saltash the utmost gaiety prevailed. Flags were suspended from the houses, the church bells rang merry peals, and the inhabitants showed the greatest anxiety to do proper honour to the occasion.

A Busy Scene.

The next process was to raise the girder to its final position, the pier being as yet only partially built. To effect this, three hydraulic presses had been placed under each end of the girder, and the tube was by them lifted 3 feet at a time at each end, thus zig-zagging upwards to its final resting-place. This operation was necessarily slow, as sufficient time had to be allowed for the masonry of the pier to set firmly after it had been built up under the girder; but by July 1858 the first girder had been erected to its full height, and the second was at the same time ready for floating into position. The arrangements for this operation were generally similar to those already described, but the course to be traversed was more intricate. Brunel himself was prevented by illness from supervising the work, his place being taken by an assistant, under whose care all was safely completed and the girder duly raised to the same level as its companion.

Raising the Girders.

In the final form of the bridge the two large girders stand with their shore ends on piers having arched openings, through which the single line of railway passes. The ends over the centre of the river are supported by four hollow octagonal cast-iron columns, 10 feet in diameter, resting on the circular granite pier built in the river-bed, two columns supporting each girder. At the end of the tubes, bed-plates and rollers are provided, admitting of free expansion and contraction under varying temperatures. Of the side spans no special description is necessary, their form of construction being apparent from the illustrations. They form sharp curved approaches

Details of the Bridge.

VIEW THROUGH THE BRIDGE.

Photo, Great Western Railway Company.

to the main spans, and from them passengers in trains crossing the bridge secure an excellent view of the structure. Although not associated with its construction, it may not be out of place to mention, as indicative of the size of the bridge, that a large gang of men is required to paint it completely during the summer months. This is usually done once in five years, and the cost to the Great Western Railway Company—the present owners—is about £1,200. The bridge contains 2,650 tons of

wrought iron and about 1,200 tons of cast iron, 17,000 cubic yards of masonry and brick-work, and 14,000 cubic feet of timber.

The total cost of the bridge was £225,000—a very moderate figure in view of the magnitude and difficulty of the work. His Royal Highness the late Prince Consort (after whom the structure was named) performed the opening ceremony on May 3, 1859. Unhappily, Brunel was prevented by illness from attending the function. Indeed, the circumstances under which he saw his completed work for the one and only time are so pathetic as to call for reference here. It is related that, one morning in 1859, a carriage truck was slowly drawn across the bridge. On this vehicle was a couch, and on the couch lay the great engineer whose name must for all time be coupled with some of the engineering wonders of the world. It was the only occasion on which he saw his bridge in its final form, and on September 15 following the world was the poorer for his loss.

A Pathetic Incident.

Shortly after his death some of his friends on the board of the Cornwall Railway placed on the land archways, in raised letters, the inscription, "I. K. Brunel, Engineer, 1859."

THE COMPLETED BRIDGE. *Photo, Great Western Railway Company.*

H.M.S. "GLADIATOR." *Photo, S. Cribb, Southsea.*

The Story of an Extraordinary Feat of Marine Engineering.

THE wintry weather that afflicted Western Europe and the British Isles in the latter part of April 1908 will long be remembered, at least by meteorologists. At a time of year which we are accustomed to associate with bursting buds and warm spring sunshine, a terrific snowstorm swooped down upon this part of the world. In a few hours on April 25 several inches of snow fell, blocking many English roads, and for a while interrupting communication. Such a fall at that season cannot be matched in the records of the Weather Office.

Sinking of H.M.S. "Gladiator."

This storm was responsible for a terrible disaster to a ship of the British Navy. While the blizzard was at its height, the liner *St. Paul*, groping its way down the Solent, collided with H.M.S. *Gladiator*, a 6,000-ton cruiser of the "Scout" class, which eighteen years before cost the nation considerably over a quarter of a million pounds sterling to build. The bows of the *St. Paul* caught her obliquely, and ripped off her side plating from top to bottom for a distance of 50 feet. Thanks to her watertight bulkheads, the liner, though grievously injured in the bows, was able to make port, but the *Gladiator* began to sink at once. All that her unfortunate commander could do was to run her into shallow water before she should settle down finally. In a very few minutes the cruiser touched bottom, and heeled over on a shelving beach till her masts were horizontal, pointing towards the shore, in water of such a depth that at high-tide her port side was just uncovered.

About two years before this disaster desperate efforts had been made to save the first-class battleship *Montague*, which ran on

to the rocks of Lundy Island. The heavy 50-ton guns were got off by the Liverpool Salvage Association vessels under the command of Captain F. W. Young, but rough weather broke up the ship itself, and the £200,000 spent in attempts to float her were wasted. However, the fight had been a very plucky one, and, but for unfavourable sea conditions, would probably have had a successful issue. So when the *Gladiator* mishap occurred, the Admiralty applied for help to the Liverpool Salvage Association, which patriotically placed at the nation's disposal the three salvage vessels *Ranger*, *Plover*, and *Enterprise*, besides a number of lighters and an extensive pumping and air-compressing plant, all of which existed principally for the purpose of assisting such of the Association's own ships as might get into trouble.

THE "GLADIATOR" ON HER SIDE AFTER THE COLLISION. *Photo, S. Cribb, Southsea.*

Scheme to raise the Vessel.

In a very short time after the collision Captain Young and his outfit reached the Solent. The wound in the *Gladiator's* side was too large to be stopped, even if it could have been reached—which

WAVES WASHING OVER THE "GLADIATOR" AT HIGH TIDE. *Photo, S. Cribb, Southsea.*

was impossible while she lay on her beam ends. But a scheme was soon formulated for righting her, floating her, and bringing her to Portsmouth dock for repairs.

Salvage Gangs at Work.

The difficulties to be overcome were indeed formidable. The shore shelved steeply, a circumstance which caused the fear that the strong ebb-tides, running at 9 miles an hour, might carry the vessel into deeper water and make her rescue a very much more arduous task. So the salvage gangs first gave their attention to the task of dragging her nearer the shore. To make this operation easier, all equipment and fittings that could be removed were detached from the wreck. The *Ranger*, with her powerful steam-winches, came alongside and swung off the 15-ton guns, and then cleared away the funnels, boats, and much miscellaneous top-hamper. This reduced the total weight considerably. But before the vessel could be drawn along the bottom it was necessary to blast away with powerful explosives the steel plating which had been turned outwards by the bows of the *St. Paul* like the lid of an opened sardine tin, and now had a firm grip of the hard sand.

A DIVER ON THE NEARLY SUBMERGED SHIP.

Photo, S. Cribb, Southsea.

The next move was to increase the buoyancy of the ship and provide powerful winding tackle on shore. Gunboats carrying powerful steam-pumps were moored on the shore side of and at right angles to the deck of the *Gladiator*, and divers then introduced the suction pipes of the pumps into the internal water-tight compartments. Meanwhile there had been constructed at Portsmouth dockyard two large steel cylinders 50 feet long and 12 feet in diameter, each having a buoyancy of about 110 tons. Their exterior was protected against damage from collision by wood sheathing and thick matting. These huge floats—or "camels," as they are technically named—were for attaching to the vessel under water on the starboard side of the deck by steel cables 9 inches in circumference, passed right under the ship and made fast to strong purchases bolted to the plates of the port side.

Lifting "Camels" built.

PLACING A "CAMEL" UNDER THE SHIP.

Photo, S. Cribb, Southsea.

Some of these huge floats were 75 feet long and 12 feet in diameter.

On shore there had been erected two very powerful steam-capstans,

secured to a solid foundation of 900 tons of concrete. From the capstans, to stout chain cables passed through the hawse pipes at the bows of the cruiser, stretched very strong wire ropes, each able to stand a strain of about 400 tons.

feet until she lay parallel to the shore. At this point her forward bridge fouled with the bottom, and operations came to a standstill while the obstruction was being removed with the aid of pneumatic tools. A second spell of hauling brought her 10 yards nearer shore,

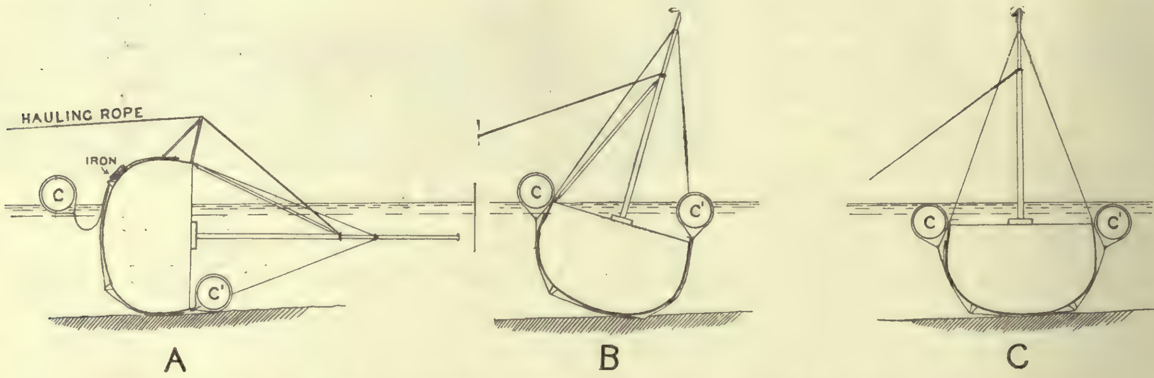


DIAGRAM TO SHOW PURPOSE OF "CAMELS" AND TRIPODS.

A, "Camels" fixed (c in its first position). B, Vessel nearly righted; tripods removed. C, After ropes of "Camel" c′ have been shortened to bring vessel quite upright.

The Ship hauled Shorewards.

When all was ready the pumps began to draw water in cataracts from the interior of the vessel, while air-compressors forced the water out of the camels. Simultaneously the capstans got to work, and sundry tugs lent their assistance. The combined effects of increased buoyancy and haulage were soon felt, and the *Gladiator's* bows swung slowly round for 6 and then the winding cable gave way; so she was allowed to remain in this position while preparations were made for the more difficult process of bringing her on to an even keel. For this task the shore capstans were of no use, as the masts, which would give the necessary leverage, pointed landwards. The *Ranger* and *Enterprise* were accordingly brought up and moored by 7-ton anchors, in line with the two masts, and at right angles to the cruiser, some 100 yards away from her.

THE MASTS ABOVE WATER—TUGS PULLING ON ROPES OVER TRIPODS. *Photo, S. Cribb, Southsea.*

The Operation of Righting the "Gladiator" commences.

Since a direct pull on the masts would have tended to drag the vessel into deeper water, two great tripods were erected on the port side, abreast of the masts. Over their tops passed the hauling ropes from the salvage steamers to the mastheads, so that the pull on these last might be obliquely upwards.

Five more camels were constructed and attached to the *Gladiator*, three on the starboard and two on the port side. The two last were intended merely to prevent the vessel coming over too far to port when she should be righted, and the cables attaching them to the port side bilge-keel were of such a length as to become taut only when the decks should be level. The three diagrams (page 44) will explain the arrangement of tripods and camels, and their positions at the beginning and end of the operations. To make the cruiser come over more readily, 250 tons of pig-iron were piled on the port bilge-keel.

The preparations completed, the steamers began to heave on the cables, and the pumps to draw water from the vessel at the rate of 6,000 tons an hour. The air-compressors expelled the water from the camels on the starboard side, and soon the masts rose above the water. Our illustrations show the various stages of this part of the operations. When the masts were about 20° from the vertical, further progress demanded that watertight wooden walls should be built to enclose part of the upper deck and the bases of the smoke-stacks. Divers screwed stout beams to the deck and nailed upright planks to them, and caulked all seams. Some pumps were now transferred to the *Gladiator*, among them two driven by petrol motors.

THE "GLADIATOR" HALF RIGHTED. *Photo, S. Cribb, Southsea.*

The shock to the *Gladiator* at the time of the collision had sheared a number of rivets in the bulkheads, and otherwise rendered many

SCENE ON THE BATTLESHIP AFTER PUMPS HAD BEEN TRANSFERRED TO HER DECK.

Observe the wooden caissons round the ship. *Photo, S. Cribb, Southsea.*

of the compartments so leaky that the inflow of water almost counteracted the utmost efforts of the pumps. A thorough examination of these minor damages was made by divers. As the leaks could not be staunched with metal, resort was had to the expedient of distributing straw in the compartments. The suction of the pumps drew the straw to the points of leakage, against which it was held by the pressure of the water outside. Any one who has experienced the difficulty of filling a garden syringe with water in which a number of leaves are floating will appreciate the efficacy of the principle.

A Pumping Difficulty overcome.

The pumps now had a much fairer chance, and in due course the masts of the *Gladiator* were once more vertical. But it was difficult to keep them so, as the starboard camels, having now reached the surface, exerted a less effectual pull. Captain Young therefore decided to shorten their cables and bring them nearer the keel. To allow this to be done, the strain on the cables was relieved temporarily by transferring the camels' burden to the *Ranger*, while the cylinders were sunk and their cables hauled in to make a shorter sling under the vessel. The operation was carried through very successfully, and checked the list to starboard.

Matters were now far enough advanced to

The Ship starts in Tow for Portsmouth.

justify an attempt to tow the cruiser into Portsmouth Harbour. The two bow camels on the starboard side having been removed, the *Enterprise* took their place, while the *Ranger* was made fast to the port bow. On the morning of October 2, 1908, the cruiser, assisted by the rising tide, and emitting foaming cataracts from the nozzles of the powerful centrifugal pumps, began to move slowly down the Solent. A guard of torpedo boats was in attendance to stop all traffic, the wash from which might have been dangerous. When the tide turned, two tugboats fastened on to the salvage steamers to help to fight the strong currents.

The "Gladiator" safely docked.

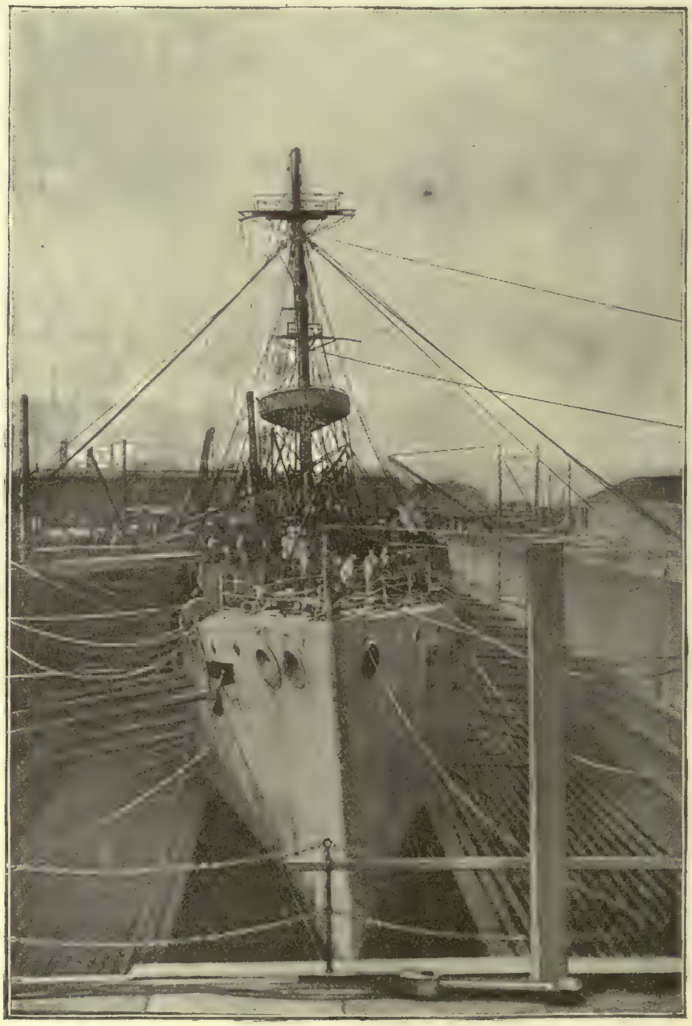
By this time night had fallen, and rendered extremely difficult the task of piloting five vessels abreast through a channel which even in the daytime is dangerous on an ebb-tide to a single large ship. But the *Gladiator*, once afloat, had to be got home. The pilot, steering his strange flotilla with the utmost skill, brought it into harbour, where the *Gladiator* was allowed to ground until the next tide made it possible to tow her into the approach to the graving dock that had been prepared for her. At the entrance to the dock it was discovered that she drew too much water to pass on to the keel blocks. She had therefore to be lightened by the removal of her cabin fittings and

THE "GLADIATOR" IN DOCK, WITH SALVAGE VESSELS MADE FAST ON EACH SIDE.

Photo, S. Cribb, Southsea.

the construction of another cofferdam between the main and upper decks. Thanks to the extra buoyancy thus obtained, and to an unusually high tide, she was berthed safely two days later.

The salving of the *Gladiator* was a fine piece of engineering, and reflects the greatest credit on all who had a hand in it. The progress of the operations was watched by a large public through the medium of the newspapers, and universal satisfaction was felt when the vessel had been safely docked. But alas that our story should have a lame ending; for after a thorough inspection the fiat went forth that the warship's damages were such as to render the cost of repairing them undesirable. The *Gladiator* had therefore to be struck off the list of warships.



THE "GLADIATOR" DOCKED FOR REPAIRS.

Photo, S. Cribb, Southsea.

THE ROTHERHITHE TUNNEL.

BY E. H. TABOR, M.Inst.C.E.,

Resident Engineer in Charge of the Construction.

A description of the largest iron-lined subaqueous Tunnel in the world. The opening of this new passage under the Thames has greatly facilitated road traffic between the Eastern and South-eastern Districts of London.

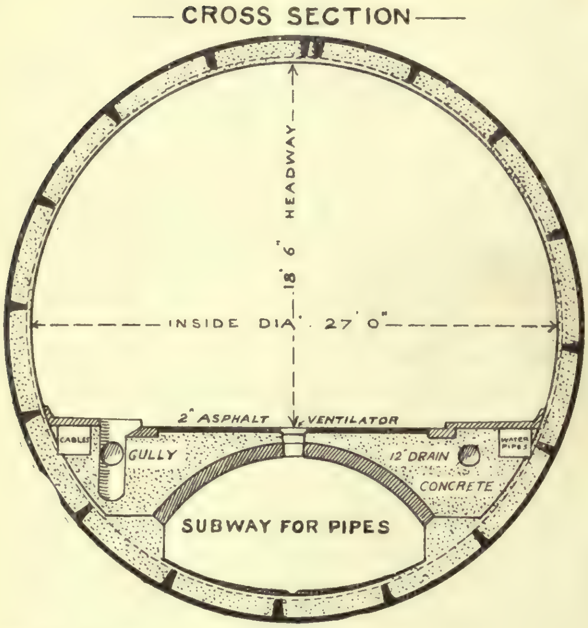
OPEN APPROACH.

"A" is the "dumpling" of earth left while the side walls were built.

IN the year 1877 the bridges crossing the river Thames in the western part of London were freed from tolls by the Metropolitan Board of Works, the predecessors of the London County Council. It was obvious at that time that the East End of London was not being fairly treated, as no free communication across the river existed below London Bridge. During the last thirty years, however, nearly all the additional accommodation provided has been for the benefit of the East End. Thus, a free steam-ferry between Woolwich and North Woolwich, a tunnel for pedestrian and vehicular traffic between Blackwall and Greenwich Marshes, and a tunnel for pedestrian traffic between Greenwich and the Isle of Dogs were opened in 1889, 1897, and 1902 respectively. To these facilities the Rotherhithe Tunnel was added in 1908.

Previous Schemes.

The provision of better means of communication across the river in the neighbourhood of Rotherhithe was proposed frequently during the last century, a ferry having been established by Act of Parliament in the year 1754 and a tunnel actually started in 1805, but never completed. The Thames Tunnel—the construction of which will form the subject of a later chapter—is only about half a



CROSS SECTION OF TUNNEL.

mile from the new Rotherhithe Tunnel, and was opened in 1842.

The Act of Parliament authorizing the construction of the Rotherhithe Tunnel was passed in 1900, but owing to difficulty in obtaining possession of the land required the works were not put in hand until 1904, when a contract was signed for its construction.

The tunnel had to be so designed as—

Description of the Tunnel.

1. To provide a roadway wide enough to allow two of the largest vehicles to pass each other, while leaving room for a sufficiently broad footpath on each side.

2. To give easy gradients to suit local traffic.

3. To be of the minimum length consistent with easy gradients—which meant that it would have to run as near the river-bed as possible.

4. To have the ends of its approaches situated in important streets, and so give easy and convenient access.

5. To be sufficiently water-tight to avoid the need for and expense of pumping.

These requirements have been met in the following way :—

Large Diameter of the Tunnel.

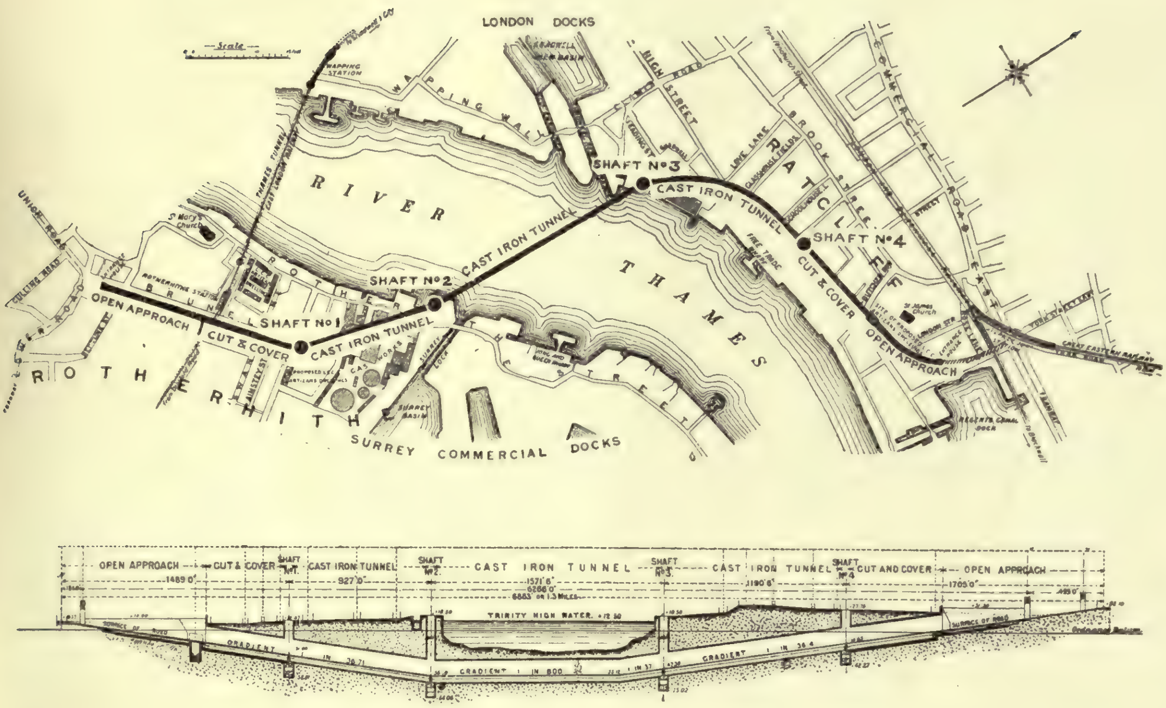
A width of 16 feet between the curbstones being taken as the minimum possible for the roadway, which is the same as that provided in the Blackwall Tunnel, the footways were made 4 feet 8 inches wide, and this, it was found, gave the cross section shown opposite. The diameter is 3 feet greater than that of the Blackwall Tunnel, and about the same as that of the largest tunnels which have been constructed for some of the stations on the tube railways.

The gradient adopted for the approaches is about 1 in 36, which is less severe than that of the southern approach to London Bridge. As the level of the roadway at the river-banks had to be about 75 feet below ground-level, each slope extends some 900 yards from the river. A glance at the accompanying plan (page 51) will show that this brings the ends of the approaches near the important streets known as Lower Road, Rotherhithe, and Commercial Road, Stepney. As executed, the total length between the centres of these streets, where the gradients end, is 6,883 feet, or 1⅓ miles nearly. The depth below the river-bed is arranged so that there will be only 4 feet of cover over the tunnel when the river is deepened to the extent to which it is anticipated that it may be dredged.

During construction there was about 8 feet between the top of the tunnel and the water. Water-tightness was ensured by building the tunnel of cast-iron plates with machined joints, which are practically water-tight, and by surrounding all the work in the approaches with a layer of asphalt.

Commencing at the southern end, the approach descends to a depth of 24 feet below the ground in a distance of 280 yards, and then crosses over the East London Railway nearly at right angles. A few yards farther on the tunnel is entered, and there follows a length

ROTHERHITHE TUNNEL.



PLAN AND SECTIONAL ELEVATION OF THE TUNNEL.

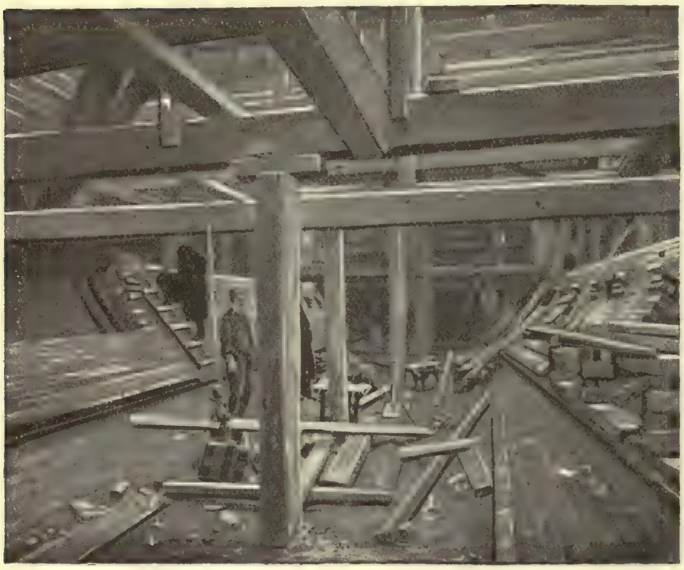
of 180 yards to the first shaft (No. 1), built on the "cut-and-cover" system, to be described later. After passing this shaft, the roadway, still descending, enters the tunnel proper, which was driven by the shield method and lined with cast iron. About 300 yards farther on, No. 2 shaft is reached, the deepest point of the tunnel, where are situated the pumps for dealing with the small amount of water due to leakage, that used for washing the roadway, and the rain-water from the open approaches. Passing through this shaft, we reach the "subaqueous" portion of the tunnel. This is nearly level, but rises slightly to give a fall to the drainage. (See plan.)

A length of 515 yards separates Shafts Nos. 2 and 3. Practically all of this length lies under the river, which is crossed obliquely in order to avoid the docks situated on each side. Near No. 3 shaft the ascent begins, the first section to No. 4 shaft being 390 yards long, and curved for most of the distance. North of No. 4 shaft there is another length of "cut-and-cover," 200 yards long, followed by the open approach, which is 360 yards in length, measured up to Commercial Road.

Open Approaches.

The open approaches consist of gradually deepening trenches or cuttings in the ground. The earth at the sides is supported by retaining walls of concrete, and the bottom, or invert, also consists of concrete. The invert is required to withstand the upward pressure of the water in the ground. On both sides of the river, just below the surface soil, is the gravel known as "Thames ballast," saturated with water, which, in the absence of a strong floor, would be forced up between the side walls.

The open approach on the south side is of special interest, owing to the fact that, as before mentioned, it passes over the East



CUT-AND COVER WORK.

on a roadway above it. The outsides of the side walls are vertical, and have a layer of asphalt applied to them; while the inside faces are sloped, or "battered." Brick parapet walls enclose the whole of the approaches.

Cut-and-cover Work.

The sections of the tunnel between the open approaches on each side of the river and Shafts Nos. 1 and 4 respectively are constructed on the "cut-and-cover" principle. This system differs from tunnelling properly so called in that the tunnel is not "driven" or bored, but the whole of the ground is first excavated from the surface down to the level of the bottom of the tunnel, which is then constructed, and the earth filled in again on the top. Where the tunnel is not too far below the surface, the cut-and-cover is the cheaper method; but of course any water met with has to be pumped, the use of compressed air not being practicable. Naturally, the land required must be purchased, together with any buildings upon it, but at

London Railway. The crossing occurs at Rotherhithe Station, where a bridge of 64-feet span carries the tunnel approach. This special construction was attended with some difficulty, as the old retaining walls of the station had to be cut through, and the approach and the bridge constructed and joined up to the old walls without interfering with the railway traffic in the station. The headway over the railway is very limited, there being only 19 feet from rail-level to road-level, and the railway traffic is very heavy. The old walls were subjected to a heavy pressure of water, which, during the construction of the crossing, was relieved by pumping. Near the bridge are provided staircases communicating with the adjoining streets.

The actual construction of the open approaches is simple. Two trenches about 12 feet wide were dug to the bottom of the foundations, and the side walls built in them. The earth between the walls (marked A, page 49), called the "dumpling," was then removed and the invert laid, and later

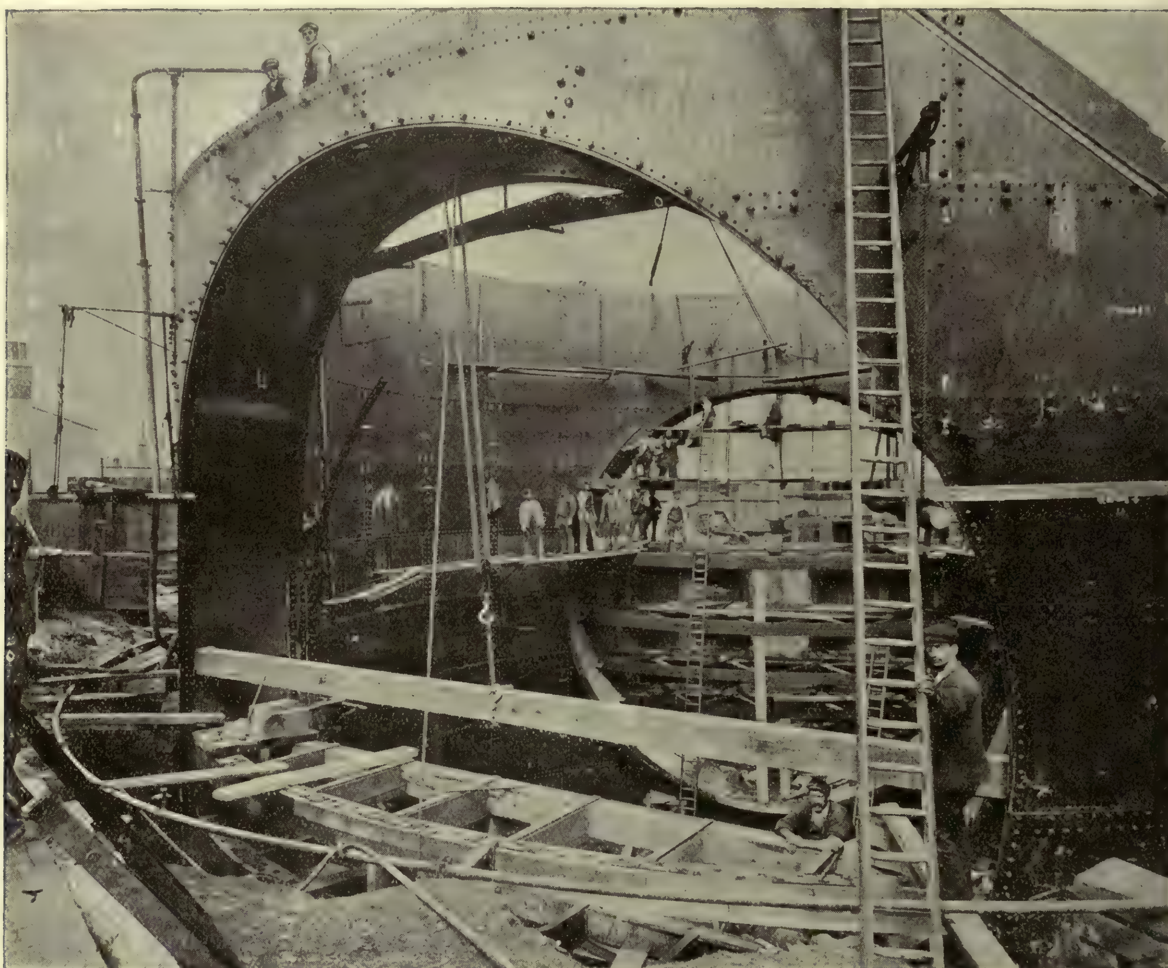
SITE OF SHAFT NO. 2.

the depth of the cut-and-cover work at the Rotherhithe Tunnel this would have had to be done in any case. After the work is completed the land is again available for building.

The trenches excavated for the cut-and-cover were 35 feet wide, and varied in depth from 35 to 56 feet. The sides were supported by heavy timbers, and the water which came in from the Thames ballast was conducted by pipes to sumps or wells, from which it was pumped to the surface. As soon as a length of trench was ready, the building of the tunnel began. Instead of iron, the lining is here of 2 feet thick brickwork in the form of a complete circle 27 feet in internal diameter. Outside the brickwork is a layer of asphalt, to keep out the water, and outside the asphalt a backing of concrete, to protect the asphalt and give additional stiffness to the tunnel.

As the masonry rose, the timbers supporting the sides were taken out, and when the arch had been completed and covered with asphalt and concrete, the space above was filled up to ground-level with earth. Great care had to be taken with this part of the work, as in many places large and heavy buildings stood quite near the tunnel, and were liable to

DECKING OF CAISSON, NO. 1 SHAFT.



SINKING A SHAFT CAISSON.

develop cracks if any settlement of the ground took place.

The faces of the tunnel where they join the open approaches are built of polished red granite of ornamental design, while the other ends of the cut-and-cover sections terminate in Nos. 1 and 4 shafts.

Shafts.

There are four circular vertical shafts, two on each side of the river. These furnish the completed tunnel with light and ventilation, and in two cases with means of access from the streets. They were also used for working purposes while the tunnel was under construction.

The Shaft Caissons.

All the shafts are of the same design, and were sunk bodily into the ground in the form of "caissons." The caissons are huge steel cylinders, built up of steel plating, 60 feet in diameter, and in one case 100 feet high. Inside each outer cylinder is an inner one 50 feet in diameter, and the space, 5 feet in width, between the cylindrical skins is filled with concrete. At the bottom the inner cylinder tapers out to meet the outer, and the two were riveted together to form a "cutting edge." Both skins vary in thickness from $\frac{5}{8}$ inch at the bottom to $\frac{3}{8}$ inch at the top. Each caisson is provided with

two circular tunnel openings 32 feet in diameter, which were plugged while the caisson was being sunk, and not opened until the tunnel was ready to pass through them.

Just above the cutting edge a steel air-tight deck or floor was fixed, right across the caisson. The floor was made up of steel plates and girders, and was strong enough to withstand the upward pressure of the compressed air confined beneath it.

In the space below the air-tight floor the men worked while the caisson sank, excavating the ground over the whole area of the bottom, and sending up the spoil through a vertical shaft or large pipe to the "air-lock" at the top. This air-shaft was fitted with hoisting machinery, and a cage ran up and down it carrying a small wagon, which on reaching the top was run out of the cage into the air-lock, and thence into the open air.

The process of building and sinking a caisson was as follows :—

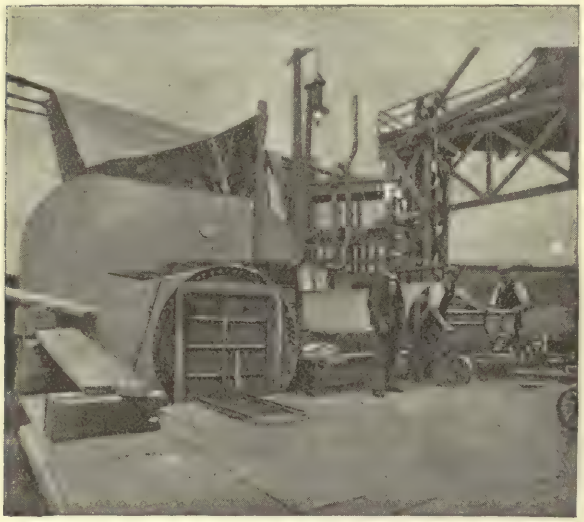
Sinking the Caissons.

A level bed having been prepared on the site of the shaft, the plates forming the cutting edge were erected on timber supports and the lower rings of plating gradually added. When about 15 feet of the caisson's height had been thus put together, the framework of the air-tight floor was fitted in, the plates being absent at this stage. All this steelwork was then riveted together and lowered gradually on to the ground, the supports being carefully removed and the caisson let down by hydraulic jacks. As soon as the cutting edge was resting on the ground, into which it sank slightly, concrete was filled in between the skins of the caisson to add weight. Next, further erection of steelwork proceeded, and at the same time excavation of the interior was started, the excavated material being hoisted out of the caisson by derrick cranes. Concreting then followed, and all these operations went on simultaneously until the work of the excavators was interfered with

RING OF TUNNEL LINING.

by the ingress of water. As it was not thought desirable to use pumps to remove the water, owing to the presence near the shafts of buildings which might be disturbed by pumping, excavation was then suspended. The erection of steelwork proceeded, and the plating of the air-tight floor was put in place and made staunch. The air-compressing and hoisting machinery was prepared for work, and connections made for the supply of compressed air to the caisson. As much concrete as possible was now filled in between the skins of the caisson in order to force the cutting edge well into the ground and so prevent the escape of the air. Compressed air was then admitted under the air-tight floor, a few pounds per square inch only at first; and the water being kept out by this means, excavation could be continued. These operations were repeated, and the caisson sank gradually, being constantly built higher and weight being added in the form of concrete. Any tendency to get out of level was counteracted by excavating most earth on the side which was highest.

When everything went favourably the caisson usually sank at the rate of about 1 foot per day, work being carried on day and night.



AIR-LOCK AT THE SURFACE.

The strata passed through were clays, sands, and a hard bed of conglomerate rock. The air pressure gradually increased with the depth, until about 20 lbs. per square inch was required. By the use of compressed air the surface on which the men worked was kept perfectly dry, and with careful regulation of the pressure little escape of air under the cutting edge took place. The total weight of the deepest caisson was about 7,000 tons.

Use of Compressed Air.

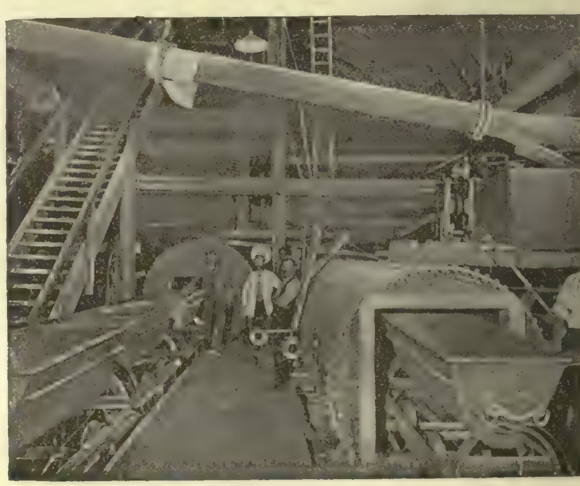
The procedure described above applies to Shafts Nos. 2 and 3, which were sunk with compressed air; in the two other caissons this process was not used, the small quantity of water met with being pumped. As soon as each caisson reached its proper level, excavation ceased, and the whole space under the air-tight floor was filled with concrete, forming an absolutely solid foundation for the shaft.

When all the tunnelling was finished, the shafts were lined with brickwork, and the two deeper ones (Nos. 2 and 3) were provided with spiral staircases giving access to the streets above, and covered in with domed roofs.

The cast-iron-lined tunnel has a total length of 1,212 yards, and is in three sections—one under the river, and one on each side.

The tunnel is lined with cast-iron plates, having very strong internal flanges, by means of which the plates are bolted together. The plates, or segments, are built up in rings, each ring being 30 feet in diameter and 2 feet 6 inches wide. Sixteen plates and one special key-piece form a ring. The key-piece has to be made in the shape of a wedge, so that it can be put in place from the inside. Each ring weighs nearly 19 tons, and there are about 25,000 tons of cast-iron lining in all. The flanges of the plates were machined on all sides, so that they might fit closely, except for a small groove or recess, formed at the inner edges of the flanges, for what is known as a "rust joint." The joint is made by filling the groove with a mixture of cast-iron borings and sal-ammoniac, driven in tightly by hammer and caulking tool. This material sets very hard, and if not disturbed forms an absolutely water-tight joint. The iron lining extends through the openings in the shafts, and is made staunch by specially prepared iron plates bolted to the end flanges of the lining and to the inner ends of the openings.

The Cast-iron Tunnel.



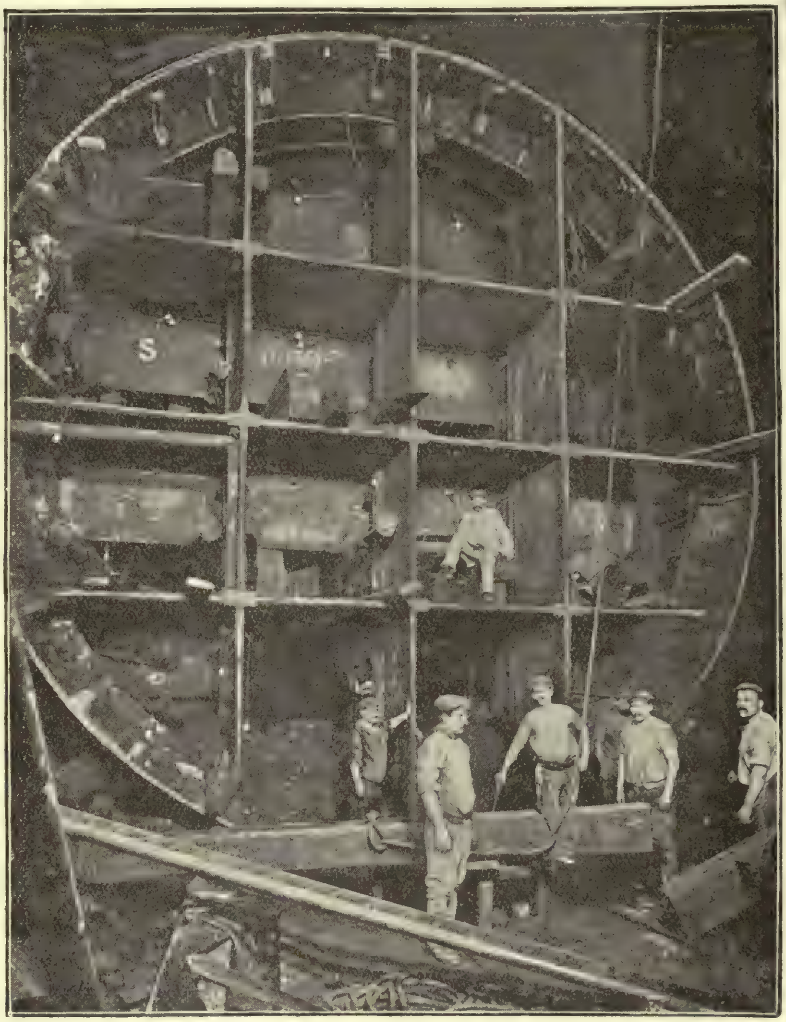
AIR-LOCKS IN TUNNEL.

Lining the Tunnel.

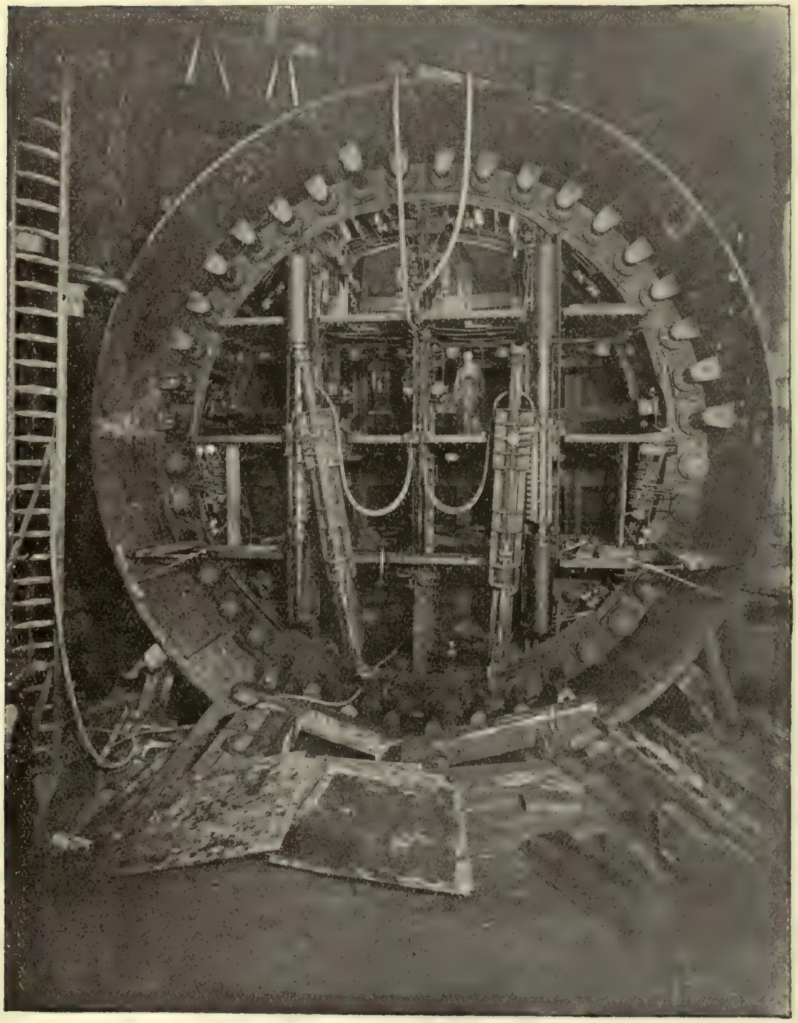
On the north side of the river the tunnel passes round a curve, as may be seen on the plan (page 51). This necessitated specially prepared iron lining, each ring of which was made taper, being slightly narrower on the inside of the curve. After the tunnel had been driven right through and the lining made perfectly watertight, it was lined with concrete. The sides of the subway under the road were then formed and the arch built, after which the roadway and the various drains, pipes, etc., were laid on the top. The last operation was to cover all the exposed face of the concrete with white glazed tiles, of which about 1,250,000 were required. The tunnel is lighted by means of incandescent electric lamps, arranged in three parallel rows.

Compressed Air used for Driving the Tunnel.

In addition to its use in sinking the shafts, as already described, compressed air was employed for driving the whole of the tunnel. In both cases the object aimed at was the exclusion of water from the workings. We have already seen that in the case of sinking the shafts the compressed air was confined by an air-tight deck or floor, and only the space below this floor, about 12 feet high, was thus under pressure. During the tunnel driving the compressed air was at first retained by a similar temporary air-tight floor fixed high up in the shaft from which the tunnelling started, so that the whole of the interior of the shaft under this floor was full of compressed air, and also the tunnel itself as it progressed. After a considerable length of tunnel had been completed, a vertical air-tight bulkhead was built in the tunnel and the air retained in front of it, the space behind it and that in the shaft being then opened to the atmosphere. The bulkhead, constructed of steel plates and girders, was fitted with air-locks for the passage of men and materials.



FRONT VIEW OF SHIELD.
S is a "safety curtain."



BACK OF SHIELD.

length, having flat ends in which were the openings for the doors. The latter were of steel, and, of course, hung so as to open towards the air pressure. Rails were laid through the air-locks for the wagons containing spoil to run along, and valves for admitting and releasing the air pressure were fitted. The principle of air-locks is described in the chapter on the Tube Railways of London.

As the machinery for air-compressing, etc., was located near the site of No. 3 Shaft, tunnelling started from that point, and the portion under the river was undertaken first.

Borings had been made as near as possible to the line of the tunnel, but there was still some uncertainty as to how far the river-bed would exclude the river water. It was therefore decided to drive a trial heading, or small tunnel, across the river, to ascertain the nature of the strata to be dealt with. This pilot tunnel was 12 feet 6 inches in outside diameter, and lined with cast iron. It was constructed by means of a shield of the same pattern as was used in the tube railways of London, and fitted with a Price's rotary excavator.* Compressed air was used and rapid progress made, the strata proving satisfactory, with the exception of a bed of rock which somewhat delayed the

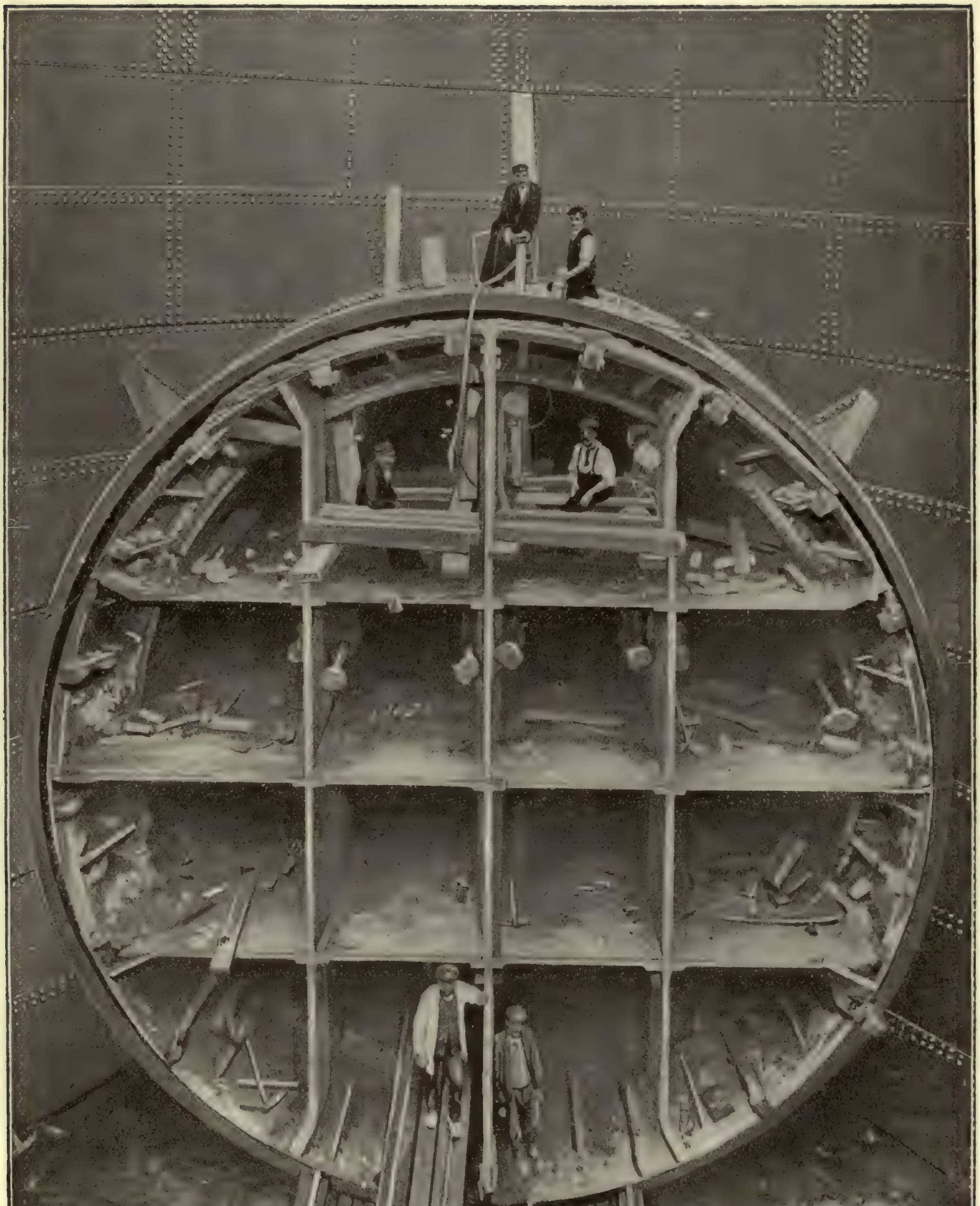
The Trial or "Pilot" Tunnel.

For compressing the air there were six powerful engines, and when work was in full swing the pumps delivered 10,000,000 cubic feet of air per day. The air was taken into the tunnel in steel pipes 10 inches in diameter, after having been cooled by means of a water spray.

Air-Locks.

The air-locks used for sinking the shaft and those fitted in the bulkheads in the tunnel were all of the same construction—a long cylinder with a door at each end of it. The cylindrical portion was about 6 feet in diameter, and varied from 10 to 36 feet in

* A description of the rotary excavator is given in the chapter on London Tube Railways.



SHIELD EMERGING INTO SHAFT

After passing under the river.

work. However, fourteen weeks sufficed to bring the pilot tunnel to within 60 yards of No. 2 Shaft, and a small timbered heading was driven for the remainder of the distance. The pressure of the compressed air was regulated to suit the tide in the river, being highest at high-water, when it averaged about 20 lbs. per square inch, and falling to 14 lbs. per square inch at low water. The materials met with were sandy clay, shells, sand, and the rock already mentioned. There was a small escape of compressed air, which showed itself in the river above in the form of bubbles, but very little water came into the tunnel.

THE TUNNEL ON CURVE.

As soon as the pilot tunnel was stopped, preparations for starting the main tunnel were at once hurried forward, and the shield, the most important of all the special appliances used, was got ready for work. A shield has been employed in the construction of all the tunnels under the river Thames, including the original Thames Tunnel.

The design adopted was very similar to that used in other large tunnels, but larger and heavier than any previously constructed. It

consisted of a hollow cylinder, 30 feet 8 inches in diameter and 18 feet long. The front part, including the cutting edge, was built up of cast-steel segments, and the rear part of steel plates riveted together. The shield was stiffened internally by vertical and horizontal partitions, which divided it up into sixteen compartments each about 6 feet square. It was forced forward by hydraulic jacks, forty in number, housed in the cast-steel segments all round, close to the outside of the shield, and whose rams pressed against the last ring of tunnel lining erected. On the back of the partitions were fixed two hydraulic "erectors" for lifting up the lining plates and swinging them round to any point in the ring of lining for erection.

The Shield.

In order to start the shield on its journey across the river, it was necessary to remove the "plug" which temporarily blocked the opening in the side of the shaft. This was done piece by piece, the earth outside being supported by timbers. As soon as the plug had been all taken out, the shield was moved up to the face, and excavation was begun. In order to move the shield, several rings of the tunnel lining were temporarily built up behind it, resting on a timber cradle specially prepared for them, and heavily shored to the opposite side of the shaft. Against the flange of the foremost of these rings the hydraulic rams pressed, causing the shield to advance. The temporary rings were removed when a few permanent rings of the tunnel had been built in.

Starting the Shield.

After tunnelling had fairly started, the method of working was as follows. A ring of lining having been erected, the miners and excavators removed the earth from the front of the shield, supporting the exposed face with timber where required. The spoil was thrown out through the back of the shield and filled into small wagons on the temporary rails laid in the tunnel. As soon as sufficient ground had been removed, excavation was suspended and pressure admitted to the hydraulic jacks. The rams of these, pressing against the flanges of the last completed ring of lining, forced the shield forward. Under favourable conditions the shield would advance the whole distance necessary for a ring—namely, 2 feet 6 inches—in a few minutes, a total pressure of 2,000 to 3,000 tons being exerted. As soon as this was done the rams were drawn in again, and the erection of the next ring commenced.

Advancing the Shield.

The shield being 8 inches larger in diameter than the tunnel lining, an annular space of 4 inches all round the tunnel was left void after the shield had passed. This was filled up with grout in the following manner. A mixture of ground lime and water was filled into a cylindrical steel vessel, known as a grouting-pan, and fitted for withstanding high internal pressure. The grouting-pan was provided with a horizontal shaft, on which iron blades were fixed, and as soon as the lime and water were introduced the shaft was rotated so that its blades, or paddles, should keep the mixture stirred. When the pan was full, an air-tight cover was fixed over the opening and compressed air of about 80 lbs. per square inch pressure admitted to the top of the grouting-pan. At the bottom there was an outlet, fitted with a tap and hose-pipe. The hose ended in a piece of iron pipe which was applied to the grouting holes, of which there was one in each plate of the lining. The tap at the bottom of the grouting-pan was then opened, and the air pressure forced the grout through the hose into the 4-inch space round the tunnel. This process was repeated until the whole space was full of lime, which set in a short time. The grouting was most important when tunnelling under the land, as by its means damage

"Grouting" the Lining.

to buildings above was avoided. We may add here that the tunnel ran below the South Metropolitan Gas Works and other large buildings without affecting them in any way.

Under favourable conditions the operations described took place four times in twenty-four hours, the shield advancing 10 feet in that time. To attain this result about seventy-five men were usually employed in the tunnel, in three shifts of eight hours each. Most of these men were accustomed to tunnelling, many of them having spent the greater part of their working lives underground. No fatal accident occurred during the tunnelling, and very little illness was caused by the use of compressed air.

MAKING RUST JOINTS BETWEEN RINGS.

Rate of Progress.

Tunnelling started from No. 3 Shaft in February 1906, and the shield reached the other side of the river in November of the same year. The conditions were similar to those met with in the pilot tunnel, and the air pressure used was about the same. The lining of the small tunnel was taken out in front of the large shield as it progressed. While the big shield was working its way under the river-bed, a second of equal size had been erected in Shaft No. 3. By the time that the first shield had run its subaqueous course, the second was ready for action, and so the

lengths between the river and the land shafts at each end could be driven simultaneously. One shield pursued its southerly way, the other bored northwards on a right-handed curve in the direction of the Commercial Road.

PUTTING IN THE CONCRETE LINING TO THE TUNNEL.

Thanks to the precautions taken by the contractors, no hitch or stoppage took place. All the tunnelling was completed by August 1907, and after the concrete lining, roadway, and tiling had been finished, the tunnel was opened for traffic by the Prince of Wales on June 12, 1908, a year sooner than had been anticipated.

A visit to the tunnel is interesting to any one who has not had previous experience of traversing such a tunnel on foot. As he approaches the top of one of the river-bank shafts he becomes aware of a rumbling noise, which gradually increases to a roar, like that of some great subterranean waterfall. Entering the dome covering the shaft he sees, far below him, lorries, cabs, omnibuses, and other vehicles, which emerge in turn from the tunnel, add their quota to the general din, and disappear again.

TILING THE TUNNEL.

A spiral staircase leads him down many feet into the depths. Far away in both directions stretch the gleaming triple rows of incandescent electric bulbs, which, thanks to the white glazed tiles lining the tunnel, give a very satisfactory general illumination. Inspired with the wish to *walk* under a river, he starts off through the echoing tunnel towards the farther shaft. Noises spring into being suddenly, and involuntarily he turns his head, expecting to see a vehicle close behind him, and is surprised to find that the nearest is a hundred yards away. Owing to the

peculiar resonance of the tunnel, it is hard to locate the cause of a noise by the ear with the accuracy possible in the upper world.

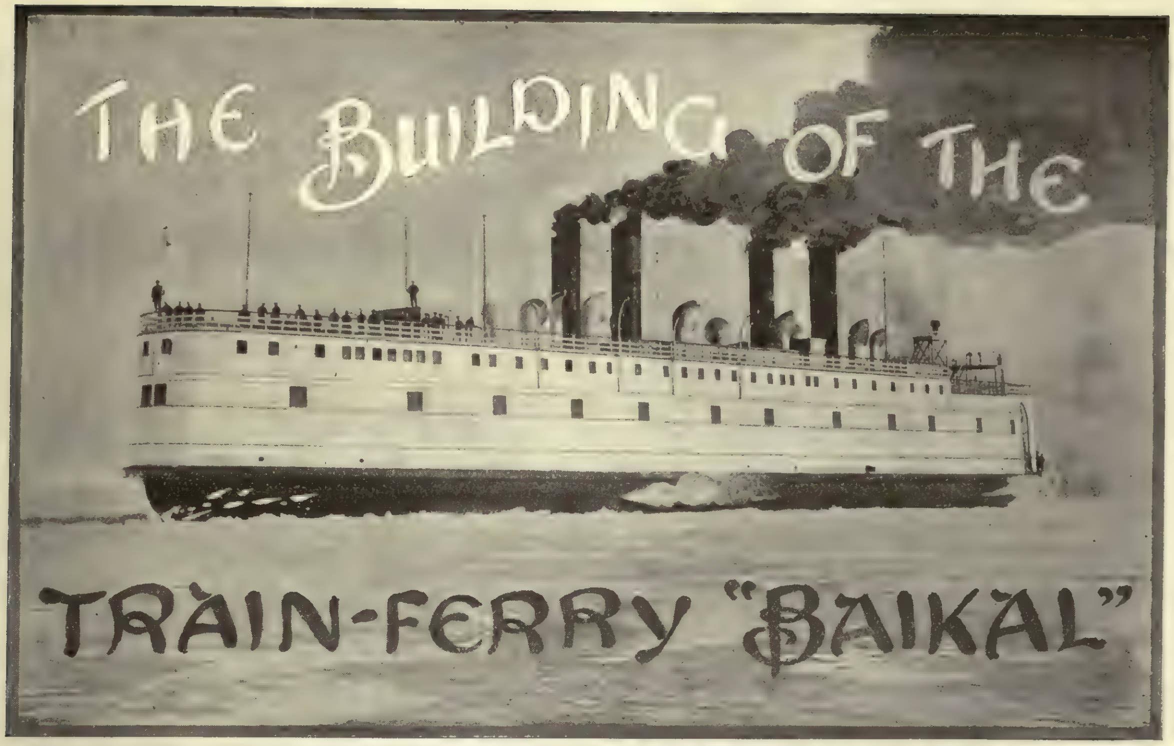
After quite a long tramp the distant shaft is reached, and many stairs have to be mounted. Presently the visitor emerges through a doorway, and finds himself overlooking wharves, where derricks are slinging cargoes into the holds of barges and small vessels. Looking back across the river, he is surprised to find how near the opposite bank seems to be—only a couple of stone-throws away. Open expanses of water dwarf distances in an amazing manner.

After this preliminary canter our traveller should seek the road entrance, and walk right through the tunnel to the farther approach. This course will give him a far better conception of the true magnitude of the enterprise than could be conveyed by the mere words of the above account; which will, we hope, in turn enable him to appreciate more fully the constructional details that are still distinguishable.

NOTE.—*The illustrations to this chapter are from photographs kindly supplied by the author.*

GAUGE ARCH.

AN ICEBREAKER AT WORK.



This illustration gives a good idea of the size of the superstructure and of the design of the vessel. (*Fig. 1.*)

BY ANDREW DOUIE,

Chief Constructor at Lake Baikal, Siberia.

Illustrated with photographs supplied by the Author.

A Unique Feat of Transport and Shipbuilding.

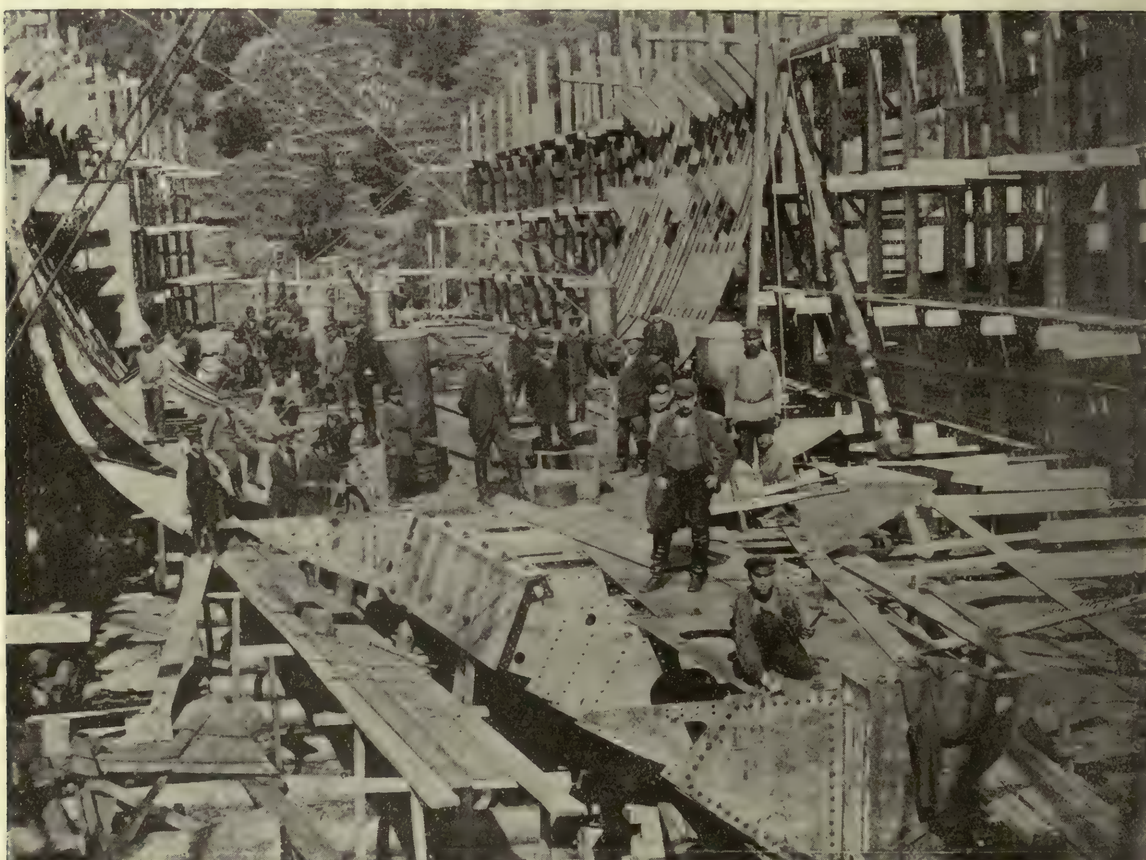
THE construction of the ice-breaking train-ferry *Baikal* in this country, its transport to Siberia, and its re-erection and completion at the village of Listvenitchnaia, on the shores of Lake Baikal, occupied a period of about four and a half years.

Before giving an account of the enormous amount of time occupied and labour expended in the transport, and the many difficulties to be overcome in the reconstruction, we may fitly give a description of the vessel herself. The *Baikal* is an example of a very unusual, and in many ways unique, type of vessel.

A Short Description of the "Baikal."

She was built by the well-known firm of Sir W. G. Armstrong, Whitworth, and Co., Limited, who have made themselves famous for ships of this description, the work being carried out at their Walker Shipyard, Newcastle-on-Tyne. The *Baikal* was built to the order of the Russian Government for the service of the Siberian Railway, and destined to transport passengers and freight cars across Lake Baikal, both in summer and winter. This lake is frost-bound for a considerable portion of the year, and consequently a powerful ice-breaking

steamer was needed to keep the traffic going. Until the line encircled the western end of the lake a short time ago, the *Baikal* formed the connecting link in the Trans-Siberian Railway between the sections west of the lake and the Manchurian extension. Her form is such as to offer the least possible resistance while working among ice. Her stem and stern are heavy steel castings, and the appearance of the vessel is similar at both ends when she is floating at her maximum draught. The structure up to the carriage deck is built entirely of Siemens-Martin steel, with frames of a heavy channel section, very closely spaced, giving a hull abnormally strong and heavy, especially at the level of the ice, where a belt of plating 1 inch in thickness and 10 feet in depth runs the full length of the vessel. The plating is flush on the outside, and additionally strengthened by a strong, solid belt of wood, 18 inches thick, extending from stem to stern. This belting forms an almost solid mass at the extreme ends, which are further strengthened by numerous struts and breast-hooks, so that the very severe shocks experienced when "ramming" in ice have no effect on the structure.



THE REBUILDING OF THE "BAIKAL." (*Fig. 2.*)

The vessel is 290 feet long, with a 57 feet beam. Her maximum mean draught is 18 feet 6 inches. She has numerous water-tight subdivisions, and a double bottom runs nearly the full length of the vessel, capable of holding about 600 tons of water ballast.

On the main or carriage deck there are three

lines of rails, running into one at the forward end, and terminating against buffers at the after end. These rails afford accommodation for twenty-five cars. The space above the centre rails extends right up to the promenade deck, which was specially arranged so as to allow for the carrying of imperial saloon carriages. The cars are run on to the carriage deck over a hinged platform connected to the shore, and secured by means of special appliances, so as to ensure their steadiness while the vessel is in motion.

Accommodation for Trains.

The superstructure, inside which the carriages are housed, covers the vessel for her full length. It is a massive erection, with a strong framework of steel girders and supports. (Fig. 1 gives a good idea of the extent of this structure.) At the forward end, or train entrance, are large folding-doors, which are closed in bad weather, thus adding greatly to the comfort of those on board, especially during the winter crossings. Ample accommodation and every creature comfort is provided for first, second, and third class passengers on the deck above, including luxuriously furnished saloons and staterooms, baths, lavatories, and all conveniences that are to be found on a first-class passenger steamer. The vessel is lighted throughout by electricity and heated by steam, no expense having been spared in providing for the comfort of all classes. There are also a private saloon and private staterooms, with up-to-date baths and lavatories. These are specially reserved for the use of any high official who may be crossing the lake.

Accommodation for Passengers.

The arrangement of the propelling machinery is one of the notable features of the vessel, which is propelled by three powerful engines of the inverted triple-expansion surface-condensing type, with all the working parts in duplicate. Two of these engines are placed aft, and one forward. The forward screw, by disturbing the water, deprives the ice of its support, and thus enables the crushing weight of the vessel to force a way more easily through the solid field ice, the form of the vessel being specially designed for this purpose. The propellers are of cast steel, and of exceptionally strong construction, the forward one being well housed and protected under an overhanging stem, which enables it to do its work without coming into direct contact with the broken ice. Steam is supplied by fifteen single-ended boilers, working at a pressure of 160 lbs. to the square inch.

Engines and Propellers.

"FREEZING-OUT." (*Fig. 3.*)

This short description of the ice-breaker and her capabilities will give the reader some idea of the magnitude of the task to be accom-

plished in transporting and rebuilding a vessel of 4,200 tons displacement at such an out-of-the-world place as Lake Baikal. An overland journey of nearly 5,000 miles had to be made before the material arrived at its destination. The whole enterprise is without precedent, as an undertaking of such dimensions had never before been attempted.

The First Erection of the Parts.

The commencement of the vessel dates back to the laying of the keel in Walker Shipyard in January 1896. There the vessel was erected, and all the different parts were carefully marked and numbered, each part having a distinguishing mark to avoid confusion. To simplify further the sorting of components at the other end, one-half of the vessel was painted white and the other black. We may mention here that the ship consisted of nearly 6,000 separate parts, and the machinery of over 1,200 parts, their combined weights totalling over 3,000 tons.

In July of the same year the material for the hull was all shipped on board the s.s. *Ardrishaig* and landed at St. Petersburg.

The Parts reach Russia.

In the following December the s.s. *Berg* unloaded the machinery and boilers at Revel, as it was now too late in the season to reach the capital. The material was all carefully checked on the Russian side before being loaded up on wagons, prior to the commencement of the second stage of the journey by rail to the farthest accessible point on the Siberian Railway. The loading up and stowing occupied a considerable time, owing to the very unusual and awkward shape of many of the parts. In several cases special trucks had to be provided; and before a start could be made, quite two months elapsed while Russian formalities were being gone through, and the Customs satisfied themselves that none of the numerous packages contained contraband goods.

After the material left the builders' works, the cost and risk of transport lay with the Siberian Railway, so that nothing more was heard of it in England until after the writer arrived in Krasnoyarsk in August 1897. Krasnoyarsk was at that time the official termination of the railway; and although the large and magnificent bridge across the Yenisei was not nearly completed, unofficial trains were running for a short distance on the other side of the river, principally occupied in carrying rails for the construction of the line, but of no practical utility for any other purpose.

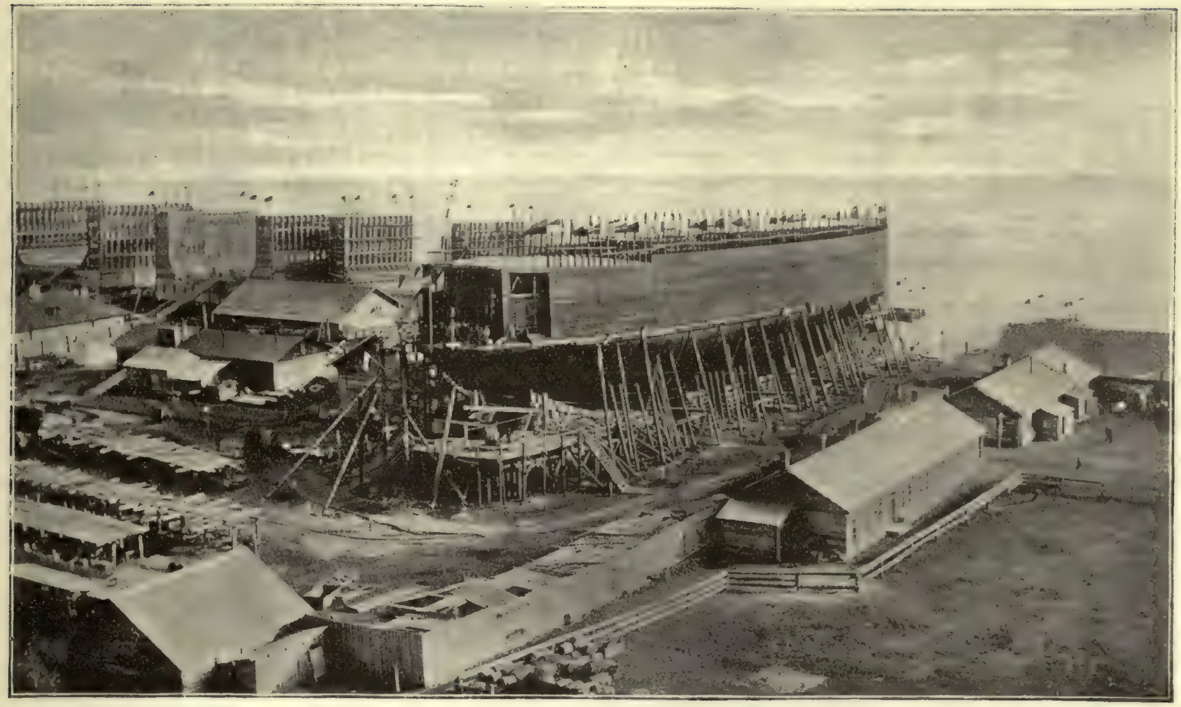
A Curious Blunder.

The material for the *Baikal* had by this time all arrived at Krasnoyarsk, and a small proportion of it had already been dispatched thence on its journey to the lake. The Russian officials responsible for its dispatch evidently came to the conclusion that the machinery would be erected first, and the ship built round it afterwards, as they had carefully sent off part of the machinery as the first consignment!

The material was all lying on the banks of the Yenisei in a confused mass, plates and angle bars, boilers, parts of machinery, pipes, cases, and all sorts of fittings intermixed, many of them embedded in the mud and hardly recognizable. A very pretty state of things for the poor engineer! A complete list was therefore given to those in charge of the transport, enumerating the order in which the different parts were to be dispatched, so as to ensure as little stoppage as possible in the progress of re-erection; but later on the writer found to his sorrow that little or no attention had been paid to these instructions.

Difficulties of Transport.

It was at this stage of the transport that those responsible for it began to recognize the many difficulties to be overcome before the different parts reached their destination. Transport by road was out of the question; the railway was not billed to reach



THE DAY BEFORE THE LAUNCH. (*Fig. 4.*)

Owing to the land sloping downwards from the water's edge, the shore end of the launching ways had to be raised several feet above the ground, as this illustration shows.

the lake before the end of 1898; so the only course left was to use barges down the river Yenisei to a point near Yeniseisk, where it joins the swift-flowing and turbulent Angara, the main outlet from Lake Baikal. By this route a large proportion of the material was taken; but it proved to be a so nearly impossible task, and occupied so much time and labour, that the railway had arrived at the lake before many of the parts had left Krasnoyarsk. The first consignment, previously mentioned as having left before the writer's arrival, showed the Russians the difficulties they had to overcome, and suggested what mode of procedure to adopt with the barges that had to follow.

It may be of interest to mention here that the Angara is one of the swiftest-flowing rivers in the world. It has a drop of 400 feet between Lake Baikal and Irkutsk—a distance of about 60 versts—and its exit from the lake is so swift that for a considerable distance it has never been known to freeze; and many dangerous and almost impassable rapids have to be encountered between Irkutsk and where it joins the Yenisei on its way to the Polar Ocean. Its rapidity is so great that its waters are far below freezing point before any ice begins to form. The Angara's most remarkable feature, however, is that it actually begins to freeze *on the bed* before it congeals at the surface—that is to say, it freezes from the bottom upwards, the current being swifter at the surface than at the bottom. In midsummer its waters are always icy cold; but by way of compensation its beautiful scenery far excels that of any other Russian waterway.

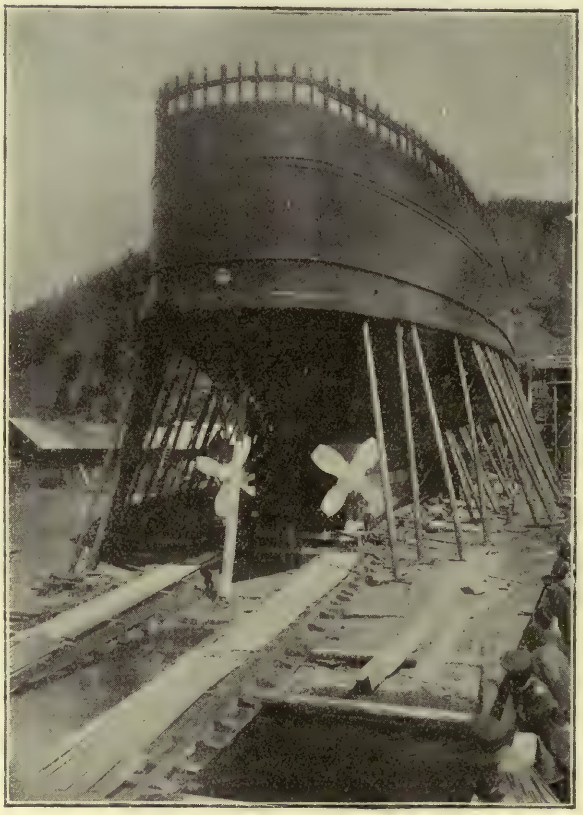
The Angara River.

The river is a very winding one, and the distance from where it joins the Yenisei to its exit from the lake is 1,700 versts. The most

difficult part of navigation on the river Angara is at the Padun rapids; and it was at this point that the barges from Krasnoyarsk came to a standstill, and all the material had to be landed. The Padun is probably the worst rapid on the river, although there are two others not far distant—the Peany and the Paghmaline—which are almost equally swift. The Russian word Peany means "drunk," and to the erratic movements of the waters at this place is undoubtedly due the name of this rapid.

From the Padun to the Paghmaline rapid is a distance of about 30 versts. The material, after being discharged at the former, was all transhipped into very small barges, and hauled with great difficulty through the turbulent waters by the united efforts of horses and men. After safely negotiating the three rapids, it was again landed and transhipped into larger barges, which were taken in tow by small steamers as far as the city of Irkutsk. These steamers should have completed the journey, but proved to be not nearly powerful enough to cope with the swiftness of the Angara where it leaves the lake, so that the barges at this junction were often delayed a week or two awaiting more powerful steamers to take them in tow and bring them to their destination. The journey from Krasnoyarsk to the lake by this route occupied about four months, and it was most important, at this season of the year, that as much material as possible should be got through, seeing that the Siberian winter would soon set in and bring all transport to a standstill. This fact was readily recognized by the many workmen now employed, and they toiled so well that by the middle of November some seven or eight barges had found their way through to the Baikal Lake. The importance of this will be better understood when it is stated that the next consignment did not reach the lake until the end of July in the following year.

Barges delayed by the Strong Current.



STERN VIEW OF THE "BAIKAL." (*Fig. 5.*)

The ice-breaker *Baikal* was rebuilt at the extreme east end of the beautifully-situated village of Listvenitchnaia, stretching along the lake from the mouth of the Angara for about two versts, a straggling row of log-houses, with a background of forest-clad mountains intersected by beautiful valleys and small rivers. These rivers become raging torrents in the spring of the year, when they drain the hills of their winter covering and empty their icy waters into the lake.

A long stretch of level ground between the foot of the mountains and the lake was chosen as the building site. It had one draw-

back—namely, that instead of affording a gradual decline to the water's edge, it sloped the other way, and this necessitated the construction of a strong wooden platform to act as a building berth, the platform being raised 11 feet at the forward end (see Fig. 6) so as to give the desired fall between that point and the water for the launching of the vessel. Owing to the great weight

The Site of the Shipyard.

THE LAUNCH. (*Fig. 6.*)

it had to bear, and to the softness of the ground for work of this description, a very strong erection had to be built; but this was so well and efficiently constructed that at no period of the building of the vessel did it show any signs of weakness.

As will be seen in Fig. 6, quite a small shipyard had been started. It may be necessary to mention here that no woodwork for the building of the *Baikal* was supplied with the other material; consequently the timber had all to be cut and prepared on the spot. This was a comparatively easy matter, as the impenetrable forests surrounding the lake afforded an abundant supply of wood both for the ship and the buildings.

Fig. 6 shows clearly a number of the temporary workshops. The large one on the left of the gangway housed all the ship's machinery, which arrived in a very rusty and deplorable condition. Months were spent in sorting it and putting it in a fit state to go into the ship. The other buildings comprise blacksmiths', joiners', and fitting shops, foundry, etc.; and farther to the left are a sawmill and a large wood-storage yard.

As previously stated, a large quantity of material had arrived at the lake by November 1897, and in January of the following year the keel was laid; but owing to an exceptionally cold season, very little work could be done. Once the Siberian winter sets in, there

is no break in the intense cold for months, the thermometer often standing at 40° below zero, while the piercing winds which sweep across the lake aggravate the cold to such a degree that at times it becomes almost unendurable. The writer spent three winters on the shores of the lake, and so can testify to the extreme severity of the climate.

The Intense Cold of a Siberian Winter.

made, and great delay was then caused by the absence of certain plates and angle bars. We had the middle of November 1898 upon us before the whole of the ironwork necessary for the completion of the ship had arrived at the lake. That means that its journey from Newcastle occupied two years and four months! However, considering all the drawbacks and disadvantages of the place, a fair amount of work had been done in the meantime—so

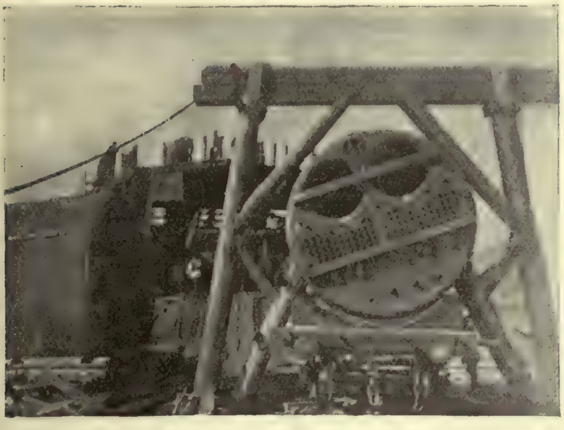
THE "BAIKAL" FINISHING. (*Fig. 7.*)

It is an interesting fact that, when the thermometer registers more than 16° below zero, all iron work practically comes to a standstill, as no riveting or caulking can be done below that temperature. The cold makes the material so brittle that it cannot withstand heavy blows, and the contraction of the too-rapidly cooling rivets is so sudden as to render satisfactory workmanship very uncertain.

April arrived before a good start could be much, in fact, that by the end of November the vessel had been "framed out."

Up to this time all the work had been done by local labour, but, as its volume increased, ironworkers and joiners were brought from St. Petersburg. These men received a much higher wage than the natives, and this caused a good deal of bad feeling, resulting in occasional bloodshed and murder,

Labour Troubles.



REMOVING BOILER FROM TRUCK. (*Fig. 8.*)

in which the imported workmen, being much in the minority, furnished the majority of the victims.

Although many of the natives were quite unaccustomed to this class of work, they picked it up so rapidly that before very long they were just as useful as the "professionals." The Russian workman in this part of the world is a sort of Jack-of-all-trades, his kit of tools consisting of a hatchet and sometimes a saw. With his hatchet he can do almost anything, from chopping firewood to dove-tailing and carving. He is a very handy man —when he has not looked upon the vodka bottle.

Fig. 2 shows the vessel with some twenty-odd frames erected. The process of framing was very slow. All the appliances were of a very primitive nature. There were no steam-winches or overhead cranes, and everything had to be done by hand under very close supervision. As the frequent mistakes caused much delay, it was quite out of the question to have the work "rushed," as the Russian workman goes his own pace, and nothing short of an earthquake will make him move faster. He never does on Monday what he can put off till Tuesday, and the word "Zaftra," which, like "Mañana" —a word very popular in Spain—means "to-morrow," is often heard.

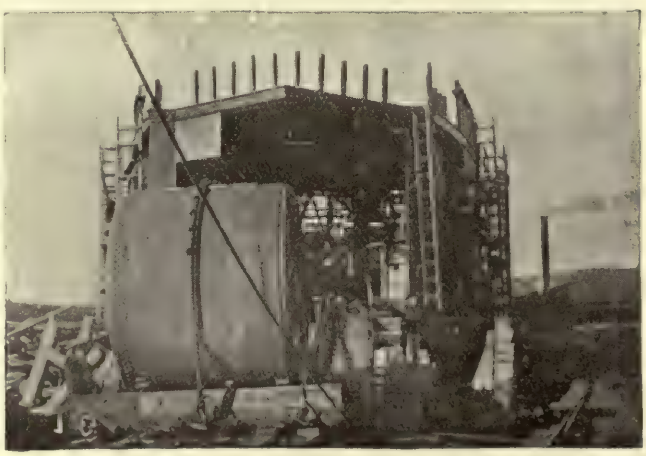
Framing the Vessel.

The early part of the winter of 1898–99 was not quite so severe as the previous one, and enabled the work to proceed at a fair pace. After the framing had all been "faired" in place, a commencement was made with the plating of the sides, and the double bottom was completed. The lack of appliances at this part of the structure was a great drawback, and a lot of extra labour had to be employed, there now being 700 men at work. The shell plating was heavy and cumbersome to handle, especially at the ice belt, and much difficulty was experienced in getting some of the plates into their proper position.

The Plating.

The men were now working day in, day out, the only break being after two o'clock on Sundays. The vessel grew surely, if slowly, and the month of June saw the shell completed and a large proportion of the superstructure in place. The appearance of the vessel at this time will be best understood by referring to Fig. 4. All through the winter and up to this time a lot of work had been going on in connection with the prepar-

The Shell completed.



(*Fig. 9.*) PLACING BOILER ON DECK.

ing of the ground and the laying of the ways for the launching of the ship.

There is no tide on the Baikal, and consequently this undertaking presented many difficulties, and necessitated a foundation for the permanent ways being carried about 120 feet into the lake. At that distance out there was sufficient depth of water on the way ends to ensure the vessel being launched without any risk of accident. The extended ways were supported on

Building the Launching Ways.

"BAIKAL" ABOUT TO START. (*Fig. 10.*)

piles driven deep down into the bottom of the lake. Each tier of piles was cut off to the required distance below the water, the depth increasing as they extended out into the lake. Cross baulks were then fastened athwart each tier, and to these the permanent ways were securely fastened.

The piling was all done during the winter months, while the lake was frozen, as the strong ice formed a good foundation for the pile-driver to work on; and the piles were cut off to their required height below the surface by the process of "freezing-out." The ice was allowed, however, to attain its maximum thickness before this work was commenced.

"Freezing-out."

A short description of this freezing-out process may here be interesting.

The ice at this time was about three feet thick. In it a square hole was cut round the head of each pile to a depth of, say, 34 inches, leaving two inches of ice at the bottom of the hole. This was sufficiently strong to prevent any water forcing its way through. The hole was made wide enough to allow the now projecting head of the pile to be cut off level with the remaining two inches of ice. As the ice is cut down the water below freezes, and the hole is made deeper and deeper until the pile has been shortened to its required depth below the surface. Frequently too little ice was left at the bottom of the cutting, and the water found its way through and filled up the aperture, which in turn soon became frozen again, and the freezing-out had to be repeated. Before the cutting down of the piles at the extreme outer end had been completed, the ice began to break up, and caused the abandonment of the process. The work was, however, finished by divers, who also laid the cross baulks and fastened the ways on to them.

Fig. 3 shows freezing-out in progress. Every winter it gives employment to a large number of men on Lake Baikal. There are several small steamers on the lake—at that season of the year, of course, frozen up—and by means of freezing-out round their sides and underneath the bottom the vessels are practically dry-docked, cleaned, and painted.

The securing of the ways underneath the water caused a lot of trouble. As they were of large displacement, their buoyancy made it

THE "BAIKAL" ICE-BREAKING. *(Fig. 11.)*

The vessel is built so solidly at the ends on the ice-line that the severe shocks of ramming have no effect on the hull. She is able to crush her way with comparative ease through ice from four to five feet thick, splitting it with her sloping bows, and thrusting it sideways under and over the main floes.

very difficult to fair them, and keep them in their proper position until they had been securely fastened. Time and again they rose to the surface, and eventually heavy weights had to be cast and laid on them, these weights remaining in position until a day or so before the launch, as the very rough weather which is often encountered would otherwise most probably have displaced everything and caused a calamity.

Difficulties with the Ways.

Violent storms are often experienced, and a 6-foot sea is not infrequent on the Baikal. The waves roll in with such force that much damage is often caused along the coast-line. A number of rough pontoons had to be built, filled with stones, and sunk at the stern of the vessel, so as to form a breakwater. But for them the heavy seas would have carried away all the stern supports.

June 29, 1899, was the date fixed for the launching ceremony, and as the time drew near there was much suppressed excitement amongst the natives. The launch formed the sole topic of conversation. Many and varied were the arguments set forth as to how the vessel was to be transferred from her present position and placed in the lake. On the morning of the launch the ship and yard buildings presented a gay appearance with their brightly-coloured flags of all nationalities, the British and Russian being most prominent. People flocked into the village from the surrounding districts, from Irkutsk, and from over the lake, all anxious to see the wonderful ship which was going to forge its way through the ice and carry the trains across the Baikal Sea. They had never even imagined that such a thing could be possible; and now that the "monster" had been built on the very shores of the lake, they looked at it in wonderment, and crossed themselves piously as they waited patiently for the ceremony to commence.

The Launch.

The weather was beautifully fine, and by midday everything was in readiness. The "daggers" were then relieved of their weight, and the ship glided gracefully down the ways and out into the Baikal Sea—a most successful launch. No drags or check-ropes were necessary here, as there is a clear, uninterrupted course of forty miles before the other side of the lake is reached. The three following days were proclaimed as holidays, and as a natural sequel to the launch the whole of the village was in a state of drunkenness for the remainder of the week.

A few words here about the villagers may be interesting. The natives proper of this district are Bouriats, a very hardy race, whose principal occupation is hunting and fishing; but the majority of the inhabitants of Listvenitchnaia are a very mixed lot, a fair proportion of them being Tartars and Caucasians. These people are either descendants of exiles who have settled in the country, or are themselves exiles whose term of banishment has not expired, and whom their passports prevent from returning to Russia. After they have done a term of imprisonment or labour, according to their crime, they settle down in the Siberian villages for the remainder of their exile, and have to provide for themselves, as they receive no support from the Government. These people supplied the majority of the labour employed in the building of the ship.

The Natives of Baikal.

After the launch the *Baikal* was towed over to Baranschick, which is at the mouth of the Angara, and was then the terminus of the railway. At this place a good deal of work had been in progress for several years on an open-ended dock or harbour, projecting into the lake, to provide shelter for the vessel while loading and discharging. The railway ran right up to the head of the dock, and the cars were embarked over a hinged gangway on to the carriage deck.

In this shelter the *Baikal* remained until she had been nearly completed. (See Fig. 7.)

The railway had arrived at the lake late in the autumn of the previous year, and had brought the remaining parts of machinery and boilers from Krasnoyarsk. The main engine bedplate and auxiliary machinery were put on board before the launch, and the machinery, which had been housed and cleaned at the works, was brought across by barge and landed at Baranschick.

The outfit was now completed, and the next eight months saw us very busy getting everything on board and fitted into place.

The shipping of the boilers presented by far the greatest difficulty, and three months of hard labour were expended before they were in position in the ship. Fig. 9 shows a boiler at the head of the gangway, and just about to enter the carriage deck. For taking the boilers off the trucks a strong wooden "gantry" was erected overhead, and from this the boiler was supported (Fig. 8). The wheels were then removed from the truck and its body lowered and withdrawn. The boiler was then let down on to a sleigh, which was hauled over a snow track, up the gangway, and along the deck to the boiler-room opening, strongly planked over, and supported by shores underneath. On this platform the boiler was placed, and slung up on sheer-legs. The foundation was then removed and the boiler lowered into position. This performance had to be repeated for each of the fifteen boilers; and as

Putting the Boilers on Board.

THE LAUNCH OF THE "ANGARA." (*Fig. 12.*)

it required manual labour, many hundreds of men had to be employed on it.

THE "BAIKAL" AND THE "ANGARA." (*Fig. 13.*)

The erection of the machinery and the general fitting-out of the vessel had now made such rapid progress that on January 16, 1900, the *Baikal* steamed out of Baranschick harbour through eighteen inches of ice, and moored opposite the east end of the village.

Trial Runs.

From this place frequent successful trials were made through the ice, which by the middle of February had increased in thickness to four and even five feet in places. Although the Baikal ice is exceptionally strong, the steamer experienced no difficulty in making her way through it and opening up a canal across the lake. The early summer of 1900 saw the train-ferry *Baikal* a finished ship.

The "Angara."

In the autumn of 1898 Messrs. Sir W. G. Armstrong, Whitworth, and Co., Limited, received an order from the Russian Government for the building of a second steamer to assist the larger vessel in carrying passengers across the lake. The *Angara*, as she was eventually called, is much smaller and less powerful than the *Baikal*. Her machinery consists of one set of engines aft, with sufficient power to drive her through two and a half feet of ice, the form and design of the vessel being that of an ice-breaker.

In the middle of winter, when the ice has attained its greatest thickness, the *Angara* follows in the wake of the larger vessel on her journeys across the lake.

The transport of her parts from St. Petersburg to the lake was a matter of small difficulty as compared to that of handling the *Baikal* components, because the railway had reached the lake in the autumn of the previous year. The reassembling of the *Angara*, two months after the dispatch of the material from Newcastle, proved a much easier task than the building of the *Baikal*, thanks to the launching berth and workshops all being in readiness.

(*See page 85.*)

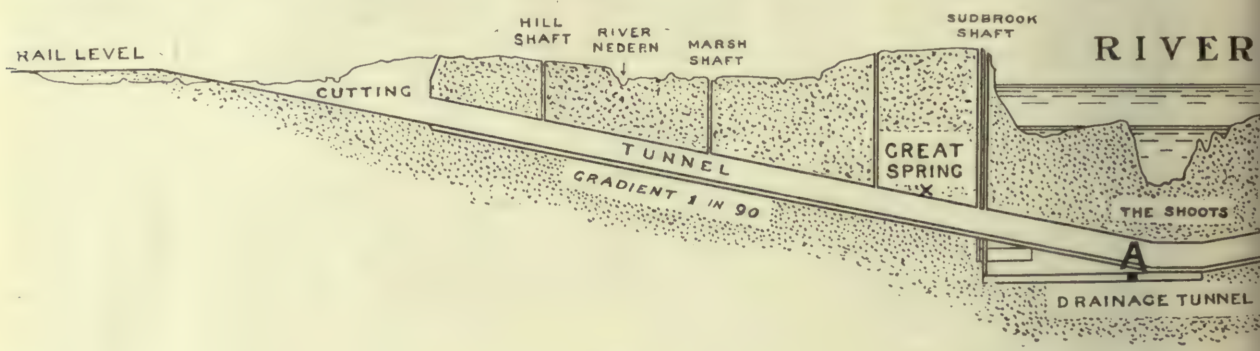
THE STORY OF THE SEVERN TUNNEL.

The driving of a submarine tunnel is generally accompanied by great difficulties, but no undertaking of the kind has taxed the resource and courage of engineer and contractor more than did the Severn Tunnel, which is remarkable as being the longest submarine tunnel in the world.

The Severn Estuary.

THE Severn estuary, while making an important addition to the total length of coast-line of Great Britain, is a very serious impediment to communication between the western counties of England and the south of Wales. It presents a funnel-shaped opening, a hundred or more miles long, up which the tides rush as into a trap, and pile up the sea-water to a height exceeded only in the Bay of Fundy. During the ebb and flow the current is extremely strong, and at low tide ever-shifting sandbanks are a source of anxiety to the navigator. In 1828 the famous engineer, Thomas Telford, threw an iron arch bridge of 150 feet span across the river at Gloucester; and some fifty years later the Midland Railway spanned it twenty-six miles lower down by a truss bridge nearly three-quarters of a mile in

length. The Great Western Railway had before this also determined to attack the great natural obstacle to a direct route from London to the South Wales coalfields and seaports, as the company was obliged either to send its trains circuitously by Gloucester, over a line troubled by some very severe gradients, or to transport them across the river on special ferry-boats at a point a couple of miles below the inflow of the Wye—an operation rendered difficult by the strong tides. Mr. Charles Richardson, who built the landing-stages for this ferry, mooted, in 1862, a project for driving a tunnel under the river a little lower down. Various other proposals were submitted to the public and to Parliament, including one or more designs for high-level bridges; but the Great Western directors ultimately decided to adopt Mr. Richardson's scheme, and secured the necessary Act for its construction in 1872.



LONGITUDINAL SECTION OF

The dark spot marked A in the drainage heading indicates

To understand the nature of the undertaking, the reader should consult the sectional diagram given above. At the site of the tunnel the river has a breadth of about 2 miles, and its bed is distinguished by a gully, near the eastern bank, known locally as the "Shoots," with nearly vertical sides, and a depth about 50 feet greater than the average of the rest of the channel.

The existence of the Shoots vastly increased the difficulties and magnitude of the project. In order to keep a sufficient amount of "ground" between the roof of the proposed tunnel and the bottom of the Shoots, it was necessary to attain a level some 140 feet below the general level of the rails on each side of the river; and to avoid gradients exceeding 1 in 90, the length of the tunnel was fixed at 4½ miles, with approach cuttings three-fifths of a mile and 1 mile long on the Monmouthshire and Gloucestershire sides respectively. To transfer the *locale* of the tunnel to London for the sake of comparison, one may imagine a train to begin its downward plunge at the Tower, enter darkness at the Bank of England, pass below Oxford Circus at a depth of 160 feet, reappear at Royal Oak Station, and regain land-level in Kensal New Town.

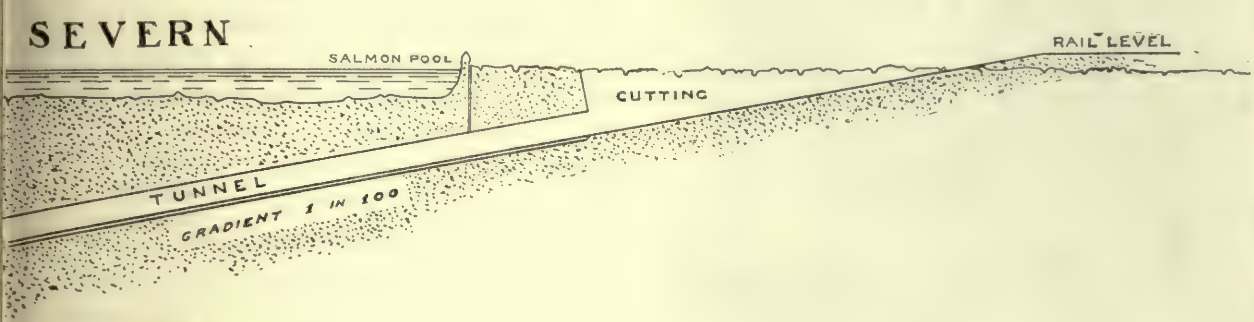
The Gradients of the Tunnel.

The inside dimensions of the tunnel were:—Height, 24½ feet; width, 26 feet.

Work begun.

Before attacking the task of driving this by far the longest tunnel in the British Isles, and the longest and largest submarine tunnel in the world, the engineers sunk a number of trial bores, which revealed the fact that the tunnel would pass through rock for at least a couple of miles, and through gravel, sand, and clay for the rest of the distance. A shaft, known as the "Old Shaft," was then sunk on the Monmouthshire side to a depth of 200 feet on the line of the tunnel, and from the bottom

of this a drainage heading was driven eastwards on a slightly rising gradient, so as to drain the tunnel at its lowest point under the Shoots. By the year 1877 about 1,600 yards of tunnel heading had been driven, and a second shaft, slightly to the north of the Old Shaft, half sunk. The directors then decided to let the contract for the tunnel, but



THE SEVERN TUNNEL.

the position of the door closed by Diver Lambert.

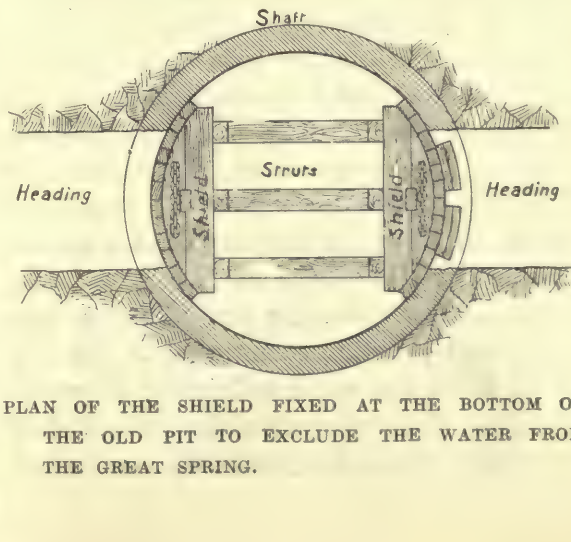
on second thoughts determined to first "prove the ground" by a heading through the whole length of the tunnel. They accordingly completed the second shaft, lined it with iron, joined it by a short passage to the Old Shaft, and installed pumps in it. The "Sea Wall" Shaft was also sunk on the Gloucestershire side, and two more—the "Marsh" and "Hill" Shafts—on the western bank. The position of these is shown in the longitudinal section of the tunnel given on page 80.

Towards the end of 1879 the first of several disasters which punctuated the history of the undertaking occurred. On October 18 the miners working westwards on the upgrade from Old Shaft struck water, which poured out in such quantities from some subterranean reservoir that the men had to run for their lives. The water, on reaching the Old Shaft, fell with a roar some 40 feet to the level of the drainage tunnel, the filling of which gave the men time to make their escape through the cross tunnel into the Iron Shaft. A few hours later the workings had been drowned completely, the water standing 150 feet deep in the shafts, up to tide level. Its sweetness proved, however, that it had no connection with the river.

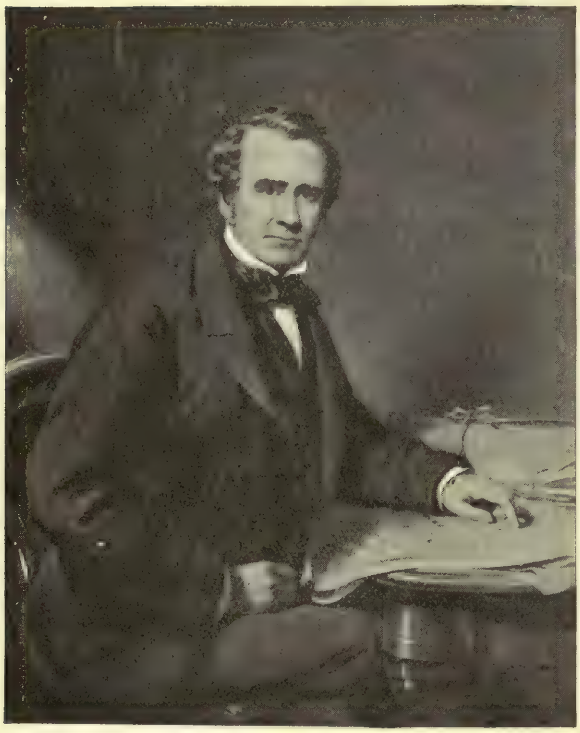
Inrush of Water from Great Spring.

Dismayed by so untimely a result of seven years' work, the directors asked Sir John Hawkshaw, their consulting engineer, to take full charge of operations. This he consented to do on condition that the contract for the completion of the tunnel should be given to Mr. T. A. Walker, who had won his spurs under him in connection with the Metropolitan Railway and the East London Railway. This condition was granted, and the contract signed at the end of 1879.

Mr. Walker at once proceeded to tackle the Great Spring, as the men named it, which had



PLAN OF THE SHIELD FIXED AT THE BOTTOM OF THE OLD PIT TO EXCLUDE THE WATER FROM THE GREAT SPRING.



SIR JOHN HAWKSHAW, F.R.S.,
Engineer-in-Chief of the Severn Tunnel Works.
(*Photo, Rischgitz Collection, from a painting by James Edgell Collins.*)

brought operations to so abrupt a standstill. Two large vertical shields of oak, having one face shaped to the curve of the lining of the Old Pit, were constructed, lowered down the shaft, and adjusted by divers, so as to block the openings of the headings into the shaft. They were held firmly up against the brickwork by stout cross beams wedged between them (page 81). In spite of the difficulties caused by the great water pressure on the divers, the shields were in position a few days after the start, and backed with bags of Portland cement carried through flap-doors in the woodwork.

Checking the Great Spring.

The door between the two pits was then closed, and pumping commenced in the Iron Pit to lower the water sufficiently to permit the repair of the pump that had failed. Unfortunately, the packing round the door leaked, and it was necessary to send down a diver to put things right. When the pumps started again one of those in the Old Pit gave way, and it soon became apparent that the capacity of the pumps was not equal to overcoming the leakage of water past the shields; and further attempts were accordingly postponed until a new and very large pump should have been added to the equipment.

Sir John Hawkshaw now decided to lower the tunnel 15 feet under the Shoots, and alter the gradient on the Monmouthshire side from 1 in 100 to 1 in 90. As the gradient on the Gloucestershire side was to remain the same, the new centre line of that part of the tunnel would have to run parallel to the original line, but 15 feet below it. Furthermore, in order to avoid increasing the total length of the tunnel, it was necessary that the depth of the Gloucestershire entrance cutting should be also increased 15 feet, which entailed the removal of 550,000 cubic yards of stuff more than had been originally estimated.

The Gradient altered.

A third shaft, 18 feet in diameter, was commenced at the Sudbrook end, close to the Old and Iron Pits, over the line of the tunnel. This was to be used for winding purposes. At a depth of 40 feet sinking operations had to be stopped for a time, owing to leakage from the adjacent pits; and the engineers had to content themselves with making a bore hole down to the heading below to drain the pit as soon as the works should have been emptied of water.

Two new shafts were also begun somewhat westwards of the point where the Great Spring was tapped—the one for winding, the other for pumping. The first of these gave a great deal of trouble, for it encountered fissured rock, from which water spouted in immense quantities. Profiting by experience, the workmen drove a cross heading from the bottom of this pit into the

Interesting Shaft-sinking Operations.

ground where was to be the bottom of the pumping-pit, excavated a space, and bricked it round. A bore hole was then sunk from the workings into this space, which served to carry away the water encountered as the sinking of the shaft proceeded from above, into the winding-pit, whence it was easily pumped to the surface.

While these works were in progress the big pump for the Iron Pit had been put in position with much difficulty, and at last started.

Pump Accident.

But, alas, for the hopes of the engineers! A few hours after the pumping had begun the new pump burst, the beam of the engine "ran loose" for a time, making a tremendous racket, and the work of months was undone in a few moments. However, undismayed by this further disaster, Mr. Walker lost no time in getting out the pump rods—great baulks of timber 15 inches square and 45 feet long, with heavy iron mountings—and the rising main, which consisted of 9-foot lengths of 40-inch wrought-iron pipes. It need scarcely be said that this was a slow and laborious task.

A new pump was ordered and installed, and a fresh attempt to empty the workings was made. This time no failure occurred, and the water was lowered 154½ feet. Mr. Walker now decided to close the door in the long drainage heading under the river, which had been left open when the Great Spring burst in. The great difficulties attending the task were, first, that the work would have to be done by a diver, as it was impossible to empty the heading; and, second, that the door was 1,000 feet from the shaft.

Three divers were engaged for the job. On

Divers employed.

the leader, named Lambert, devolved the responsibility for walking up the heading, drawing 1,000 feet of air-hose after him, closing the door in the head wall, and screwing down a 12-inch sluice-valve, so as to stop all communication with the farther part of the heading under the Shoots. To use Mr. Walker's own words, Lambert "started on his perilous journey armed with only a short iron bar, and carefully groped his way in total darkness over the *débris* which strewed the bottom of the heading, past upturned skips, tools, and lumps of rock, which had been left in the panic of 1879, until he reached within 100 feet from the door, when he found it was impossible to drag the air-hose after him, as it rose to the top of the heading, and its friction against the rock and the head-trees offered greater resistance than he could overcome. He, however, would not give up without an effort, and he pluckily sat down and drew some of the hose to him, and then started on again; but after one or two vain efforts he found it impossible to proceed, and was obliged to return to the shaft defeated."

THE LATE MR. T. A. WALKER,
Contractor for the Severn Tunnel Works.

As the use of a hose, even with two men passing it along the heading, was impracticable, a Mr. Fleuss made an attempt with his recently-patented diving equipment, which included a supply of compressed oxygen gas carried in a vessel attached to the back, to replace the usual hose and air-pumps. But as the inventor was not a professional diver he failed of his object, and Lambert had to be persuaded to try the apparatus. At the first trial he reached the door, and removed one of the wagon rails running through it before he thought it time to beat a retreat. Two days later he descended again, closed the door, and screwed down the sluice, being on this occasion under water for eighty minutes.

A Curious Mistake.

Yet even when the job had been done, the pumps seemed to have no more control over the water than before. According to calculations, the closing of the door and sluice should have given them easy mastery by reducing the inflow. When at last the drainage heading was cleared sufficiently to allow an examination of the head wall, it was discovered that the sluice-valve had, for some unknown reason, been fitted with a *left*-handed thread, so that Lambert, instead of closing an open valve, had actually opened a closed one! A few moments sufficed to correct the mistake, and the effects were immediately felt in the rapid fall of the water-level in the sump and the pumping-shafts.

The Great Spring attacked and defeated.

This trouble having been overcome, Mr. Walker now turned his attention to the Great Spring in the heading west of the Old Shaft. The door in the shield on that side was opened and the water allowed to run free. The contractor and two others on entering found a stream of water 7 feet wide and 1 foot deep flowing down the heading; and discovered that at a point about 600 feet from the shield the passage was almost choked by a heap of *débris* which the inrush of the spring had swept before it. It was decided to wall up the heading without delay. Two clay dams were built across the heading, and large wooden troughs laid from one to the other to carry off the water. In the dry section between them the wall was built round the troughs, and when the brickwork had set the troughs were removed and a wooden door substituted and closed fast. The water from the spring was thus shut out entirely from the works, and for the next two years gave no trouble at all. The year 1880 ended very auspiciously.

A Snowstorm causes Trouble.

Early in 1881 there occurred the terrific snowstorm which is still an unpleasant memory to all who experienced it. Railway traffic was disorganized by the drifts, and for ten days the tunnel works were out of communication with the coalfields. Fuel for the pumping-engines ran short, and it became necessary to cut up valuable timber, as to stop the pumping would have been disastrous.

A strike of the workmen broke out in May over the question of working hours, and, though it delayed matters for a time, had the ultimately good effect of clearing out a number of disaffected men, who, if retained, would have made trouble sooner or later.

Irruption of River Water.

As soon as things had quieted down, the work was pushed on at the bottom of the Sea Wall Shaft, where several lengths of full-sized tunnel had been "turned" or bricked round. Everything was progressing smoothly when, without warning, salt water burst into the tunnel and drove off the bricklayers. Immediately above the point of ingress there was at low tide a pool named the Salmon Pool, formed by a depression in the river-bed. Mr. Walker solved the problem of finding the leak by making a number of men join hands and wade about in the water. The sudden disappearance of one of the explorers showed its whereabouts; and the leak was stopped

by flinging into the cavity a mass of clay. It was fortunate for all concerned that the water broke in before the heading under the river was completed. Had the water had a clear run an immense amount of damage would have been done.

About this time a system of electric lighting was introduced into the works. This may serve as a reminder to the reader that in the early 'eighties the lighting and ventilation of tunnels were but primitive as compared with the methods of to-day, and that drilling machines and explosives had not been brought to their high pitch of present perfection. In short, the driving of a second Severn Tunnel of equal length would not now be nearly so difficult a matter as it was then, thanks to mechanical improvements and to the capabilities of the Greathead shield.

On the whole very satisfactory progress was made during this year, by the end of which the heading under the river was completed.

Telephones installed.

Early in 1882 the telephone was installed between the offices on both sides of the Severn. On the first day that it was in use it enabled a foreman at one end to overhear what a discontented ganger—quite unaware of the telephone's powers—said in the cabin at the other end, and to dismiss him before he could cause mischief among the men.

A Laughable Incident.

In December a somewhat laughable incident, which might easily have had serious results, occurred. At a point under the river some water had been impounded in a heading by a fall of timber, and when purposely released flowed down the heading. One of the men, on seeing it, shouted that the river had broken in again, and in a moment panic seized everybody. A disorderly stampede to the shaft took place, the men throwing down their tools and tripping each other up in their haste. Then the pit ponies, alarmed by the conduct of their masters, also stampeded, treading on the bodies of prostrate men, for whom in their terror they had lost their usual respect. Fortunately none of the 300 or 400 men were injured, and beyond the loss of sundry articles of clothing left behind in the hurry, and merciless chaffing by the rest of the workmen, nobody was any the worse for the scare.

A few months later, however, a fresh item was added to the list of real disasters. This was a second irruption of the Great Spring, which drowned out all the sub-river workings. Lambert was again called in to close the drainage heading door, and after three weeks of hard pumping the tunnel was free of water, and the spring imprisoned once more.

A Tidal Wave floods the Tunnel.

Meanwhile misfortune had overtaken the Gloucestershire works. On the night of October 17, 1882, an unusually high spring tide, increased by a strong south-westerly gale, swept up the Severn estuary, and overflowed the sea wall near the Marsh Pit. It came as a solid wall of water five or six feet high, flooded the cottages on the low ground, and rushed down the unprotected mouth of the shaft, sweeping away and drowning a poor fellow who was climbing the ladder at the time. The men at the spot made desperate efforts to raise a rampart round the pit to stem the flood, and succeeded. As the sub-river portion of the tunnel was already full of water from the Great Spring, the salt water gained quickly on the eighty-three men working in the heading to the east of Marsh Pit, which had not yet reached daylight. They were obliged to retreat up the incline, and take refuge on a stage. The water rose at the bottom of the shaft to within a few feet of the crown of the tunnel, and then the inflow was checked. A boat was hastily procured and lowered, and early next morning the last of the imprisoned men was brought safely "to bank."

The tidal wave had worked inland for more

"PANIC SEIZED EVERYBODY."

than a couple of miles, and completely filled the great cutting of the Gloucestershire approach. Had a heading existed right through from the Marsh Shaft nothing could have saved the men below.

As it was, the position of affairs looked deplorable enough—the tunnel partly, and the cutting quite, full of water, great damage done, and long delay inevitable. The contractor was already some £100,000 out of pocket over the contract.

The worst had been passed, nevertheless. There were, indeed, periodical breakdowns of the pumps and minor troubles, but work went ahead so steadily that by the end of 1883 the larger part of the tunnel lining had been put in.

Method of Tunnelling employed.

The method of tunnelling employed consisted of driving a heading, or gallery, at the level of the bottom of the tunnel, making "break ups" from this at short intervals, and from the top of these working top headings in both directions, at the level of the crown. These upper headings were enlarged and timbered where necessary; then the ground between them and the lower headings was broken away vertically; and finally the two big side benches of stuff were removed. When a length of tunnel had been thus enlarged to full section and timbered, the masons got to work, and under cover of the wooden cage built first the invert and then the side walls. Semicircular wooden "centres" were then arranged athwart the upper part of the cavity, parallel to one another, and from 3 to 4 feet apart. Beginning at the top of the side walls, the masons laid a "lagging" of stout boards 3 inches thick horizontally along the outside of the centres, which it touched, and continued the brickwork upwards in courses, carefully filling in all spaces between the brickwork and the ground. Fresh laggings were added on either side as required, and the brickwork brought up to the crown, or topmost part of the arch. For the last 18 inches the mason used short laggings resting on only two centres, and worked endways, completing the arch a few feet at a time, until only a small hole at one end of the "length" remained. Through this he made his exit, and filled the cavity afterwards from below.

The stout horizontal wooden "crown bars" and the "poling boards" behind them, which hold up the ground, are either built in or gradually drawn out endways as the brickwork proceeds and they are no longer needed. In the latter case the way must be prepared for them by excavating an adjacent length, the timbering of which is simplified by the fact that the crown bars rest on the completed brickwork at one end.

The employment of advance headings and "break ups" makes it possible to excavate and finish several lengths simultaneously; whereas if none are used, and the tunnel is excavated to full size at once, excavation and masonry must proceed alternately.

The whole of the tunnel on the Gloucestershire side, from the Shoots to the open cutting at the eastern extremity, was completed by August 1884; and by the end of the same month the section from near the Great Spring to the western entrance was also finished. There remained only a short section in the vicinity of the Great Spring, requiring special precautions.

Taking the Great Spring in Flank.

In order to divert the water, which could not be confined, Sir John Hawkshaw decided to take the spring in flank. A side heading was therefore driven parallel to the centre line of the tunnel and 40 feet north of it, on a much slighter gradient than that of the tunnel itself, so as to tap the spring at a point below the invert. While this was being done the loose bed of the little river Nedern, which was suspected as being the source of the spring, received attention in the form of a concrete invert

nearly 4 miles long—a considerable work in itself.

These two measures completely justified themselves. The side heading carried off all the water of the spring into the tunnel, through which it flowed to the Sudbrook pumping-station, and enabled the men to attack the last lengths. On October 17, 1884—the anniversary of the tidal wave disaster—the headings met, and a way was open from one end of the tunnel to the other. It happened that the chairman of the Great Western Railway paid a surprise visit that day, and so was one of the first to make the passage.

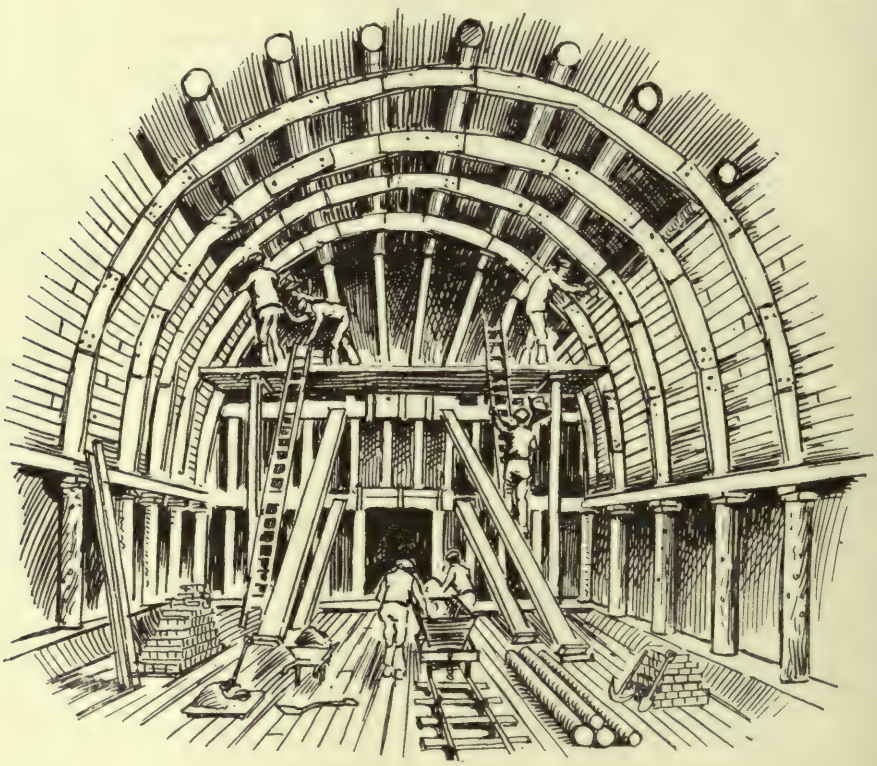
The Tunnel completed.

On April 18, 1885, at 8 a.m., the last brick of the tunnel was set. Eight weeks afterwards the sluices draining the Great Spring were closed, and water excluded from the tunnel. Three months later the first passenger train travelled under the Severn; and within forty-eight hours Mr. Walker left the scene of his arduous and anxious labours for South Africa.

But the Great Spring had not said its last word. The great head of imprisoned water produced a pressure of $57\frac{1}{4}$ lbs. to the square inch on the brickwork, which showed serious signs of not being able to stand the strain.

A Fresh Difficulty to face.

Mr. Walker was hurriedly recalled to England to deal with this fresh difficulty. After due consideration, the engineer decided to let the Great Spring have its way, and to relieve the brickwork. A special pumping-shaft was sunk at the side of the tunnel, and fitted with six large pumps to deal with the spring water. Two other stations at Sea Wall Shaft and at a shaft situated about five miles from the Gloucestershire en-



BRICKING THE TUNNEL.

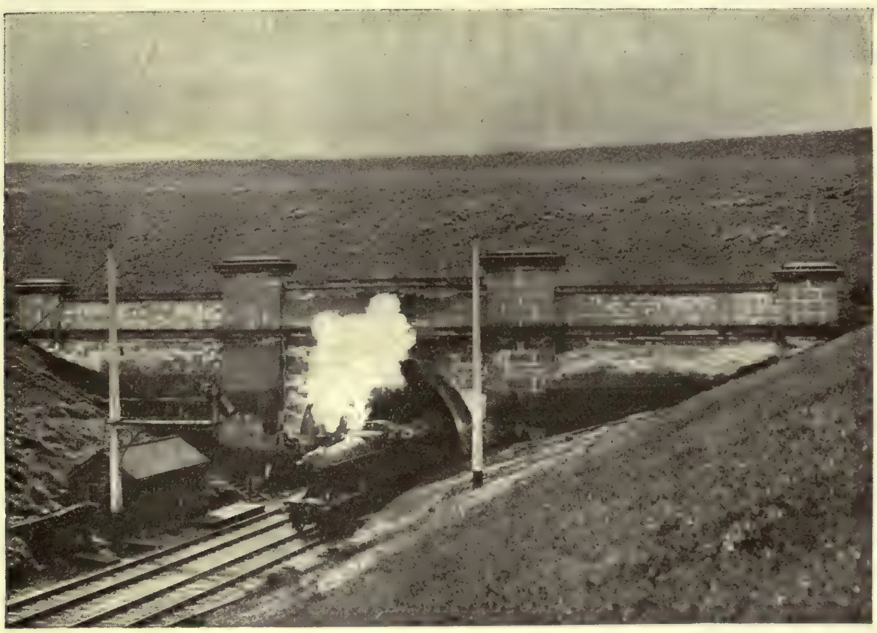
trance lift the water that finds its way into the cuttings and tunnel. Ever since the opening of the tunnel to general traffic the pumps have been ceaselessly at work, emptying some 24,000,000 gallons a day into the Severn—a quantity equal to about one-eighth of the water supply of London, and sufficient to form in one year a lake having a depth of 6 feet and an area of about 7½ square miles! Travellers through the darksome tunnel are probably quite unaware that they pass close to fourteen huge pumps, by which alone the safety of the great tube is preserved. The Severn Tunnel is a striking illustration of the extent to which a submarine is handicapped in the matter of drainage as compared with a big mountain tunnel, which can be, and is, so graded as to free itself of water by gravitation.

The ventilation of the tunnel is performed by a huge Guibal fan, 40 feet in diameter, which extracts the foul air through a shaft at Sudbrook.

Facts and Figures.

To conclude with a few striking facts and figures. The construction of the tunnel occupied fourteen years. In the busiest seasons about 3,500 men were engaged. The lining of the tunnel consumed 77,000,000 bricks — three-fifths of which were made on the spot — laid in about 37,000 tons of Portland cement. For the necessary blasting of rock 250 tons of explosives were used.

The successful conclusion of this great undertaking was a triumph for Sir John Hawkshaw, Mr. Walker, and his doughty lieutenants. There are much longer tunnels in existence, but none of them has laid a heavier tax on the perseverance and resourcefulness of its engineers and their staff.



A TRAIN EMERGING FROM THE SEVERN TUNNEL.

(*Photo, Great Western Railway Company.*)

The erection of this great steel arch across the gorge of the Zambesi, just below the Victoria Falls, supplied a much-needed link in the Cape to Cairo Railway project. Besides being one of the loftiest bridges in the world, the Victoria Bridge is situated in a spot of unique beauty, and for that reason attracts the tourist as well as the engineer.

Discovery of the Falls.

DURING his first expedition down the Zambesi in 1855 Livingstone struck the mighty cataract which the natives called Mosioatunga—" smoke sounds there " —a name suggested by the roar of this greatest of the world's waterfalls, and by the columns of fine smoke-like spray which rise ever from the abyss, and, on attaining a height of from 200 to 300 feet above the upper water-level, condense into a perpetual shower of fine rain. In honour of his sovereign the explorer dubbed his discovery the Victoria Falls.

Immediately above the Falls the Zambesi is a broad-flowing stream, more than a mile wide, with well-wooded islands. Suddenly the waters encounter a gigantic fissure of supposed volcanic origin in the black basalt, and thunder vertically downwards through a distance of nearly 400 feet. From this chasm the water escapes through a narrow opening into a deep cañon, which zigzags southwards in a most extraordinary manner, as seen in our illustrations on pages 92 and 93. The upper surface of the cañon is almost on a level with the upper bed of the Zambesi close to the Falls.

Every traveller in South Africa nowadays includes in his programme, if he possibly can, a visit to these wonderful Falls, which relegate even Niagara to a second place.

The Falls and the Bridge.

They are 1,641 miles from Cape Town by rail, and the journey, despite the conveniences of the *train de luxe* that runs twice a week, is long and tedious. Yet the reward is sufficient to repay weariness and expense. The tourist gazes spellbound on this grand freak of nature ; and when his eye is sated with the splendours of the waterfall, he finds fresh food for admiration in the remarkable arch bridge which has been thrown across the chasm below the Falls. This bridge is vested with a romance of its own—first, by its proximity to the Falls ; second, by the fact that it is one of the loftiest, if not actu-

"THIS GRAND FREAK OF NATURE."

ally the loftiest, in the world; and third, because it is the most notable feature of, and the link most difficult to forge in, a notable scheme—the Cape to Cairo Railway. We may add that from the purely engineering aspect it is of the first interest as regards its design and its erection in a locality so remote from a base of supplies.

Alternative Sites for the Bridge.

During the great Boer War the engineers of the Rhodesian section of the Cape to Cairo Railway pushed northwards manfully, heedless of disasters in their rear. Railhead was already within a few hundred miles of the great Zambesi when the relief of Kimberley enabled Mr. Cecil Rhodes to give his consideration to the question of carrying the rails across the river. The choice lay between a long, many-spanned bridge some few miles above the Falls, near Livingstone Drift, and a much shorter arch bridge flung boldly across the cañon below the Falls. Mr. Rhodes desired that travellers on the railway should have on their passage a good chance of seeing and visiting the cataract; and as financial considerations pulled the same way, decision was given in favour of the arch bridge, though voices were heard exclaiming that the intrusion of a giant structure of steel would ruin the natural beauty of the spot.

The site finally selected was surveyed in the years 1900–1901. It is situated in the first arm of the cañon, about 700 yards below the

MAP SHOWING SITE OF BRIDGE.

cataract, and inside the zone in which spray falls for several months of the year, so that the wish of Mr. Rhodes that the trains should catch the spray as they passed has been fulfilled, though the author of the wish unhappily did not live to see its fulfilment.

The Site chosen.

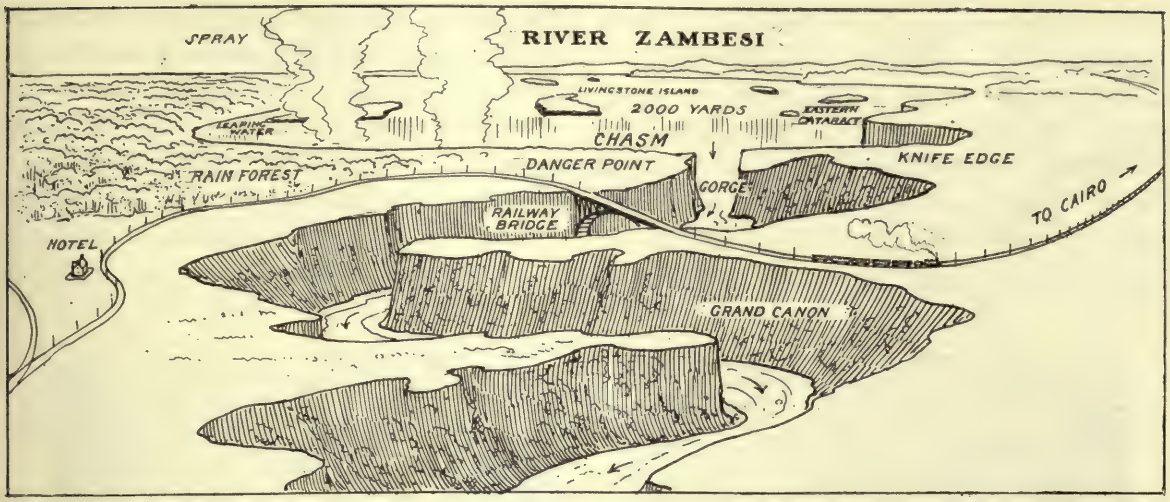
At the point chosen the chasm has a top width of about 750 feet, and narrows downwards to 400 feet at water-level. On the north bank the cliff is practically sheer, while the southern face has a shelf about half-way up, and is generally more easy of access.

The design of the bridge was entrusted to Mr. G. A. Hobson, a member of the firm of Sir Douglas Fox and Partners — a firm that has been prominently connected with engineering enterprise in Rhodesia and other parts of South Africa.

A Description of the Bridge.

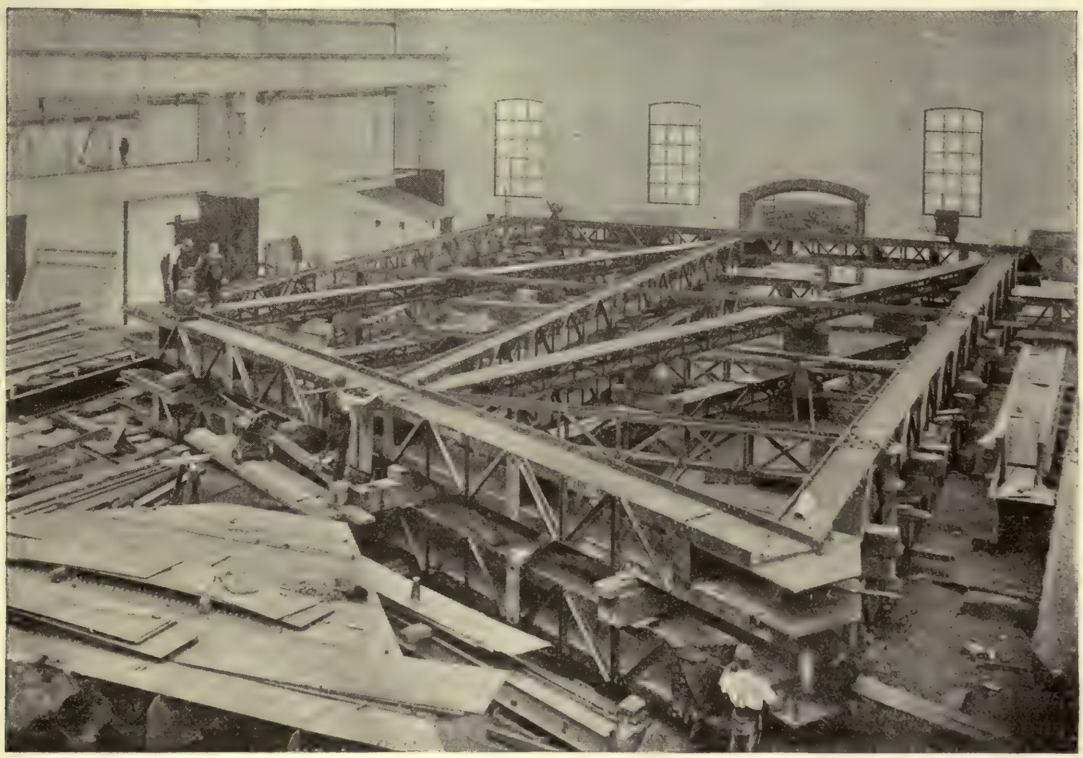
The plans finally chosen were for a two-hinged spandrel-braced arch bridge. The words "two-hinged" imply that allowances for movements due to alterations in temperature and load are concentrated on the points of support at the bottom of the end posts. Spandrel-bracing makes the horizontal top chord, over which the track is laid, the partner of the curved arch in the matter of bearing the strains and stresses to which an arch bridge is subjected, and also affords certain advantages in the erection of the members.

It should be mentioned that the bridge has, in addition to the main arch, two short end spans of 62½ and 87½ feet respectively, supported by the banks and the end posts of the arch. The arch itself is 500 feet long between the centres of the end posts, which are 105 feet high. The rise of the crown is 90 feet, so



PERSPECTIVE VIEW OF THE VICTORIA FALLS AND GORGE.

that at the centre the bridge is 15 feet deep. The vertical girders have an upward taper, or "batter," of 1 foot in 8; and the booms of the arc approach one another towards the centre of the bridge, so that the distance between them diminishes from 53 feet 9 inches at the main bearings to 27½ feet at the crown. This gives sufficient room for a roadway, 30 feet broad between the parapets, designed to carry two tracks of rails.



ASSEMBLING THE LARGEST PANELS OF THE BRIDGE IN THE SHOPS BEFORE SHIPMENT.

(*Photo, The Cleveland Bridge Company.*)

The total weight of the bridge is about 1,500 tons. With the full "live load" added, and the stresses due to the horizontal thrust of the arch, to temperature, and to wind pressure, each of the four bearings on which the arch rests is called upon to sustain a maximum thrust of some 1,600 tons. The combination of ease of movement at these four points with power to resist great pressure was one of the chief problems confronting the designer, and it received a masterly solution.

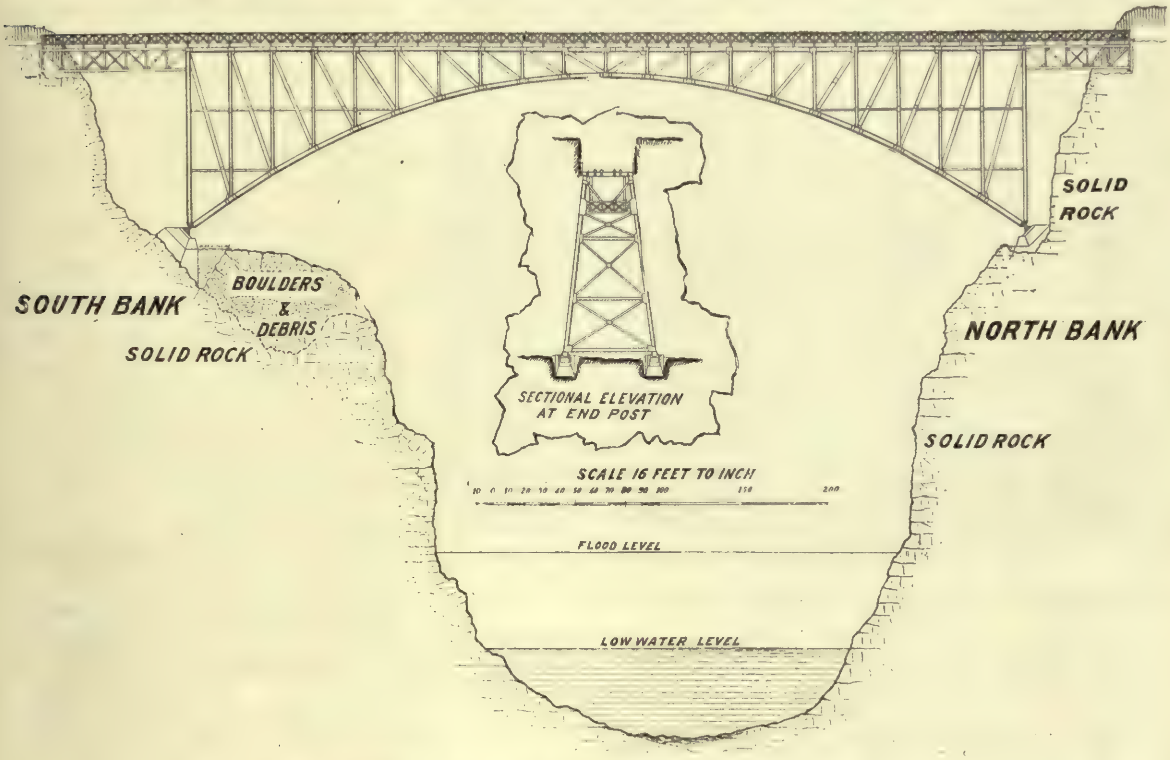
TRIAL ERECTION OF THE CENTRE PANEL OF THE ARCH. (*Photo, The Cleveland Bridge Company.*)

The Bearings and Skewbacks.

Beginning at the bottom, we find at each point of support a solid foundation of concrete, reinforced with steel bars. To this is affixed by four huge bolts, 3 inches in diameter, a massive base plate, carrying an equally massive pedestal built in six sections of thick steel plates. At the top of the pedestal is a steel forging, in which from end to end is cut a semicircular channel 1 foot in diameter. In the groove rests a huge steel hinge pin—also 1 foot in diameter—5 feet 10 inches long, pierced by a central bolt hole. Pressing on the top of the pin is a second channelled forging, named the "saddle," supporting the skewback, a beam of immense strength, in which meet an end post, the main boom of the arch, and two members of the vertical and lateral bracings.

This arrangement allows the saddle of the skewback to move circumferentially on the pin and relieve the varying stresses of the steelwork above. To prevent the pins shifting endways, each has an annular projection in the middle, engaging with corresponding

recesses in the channels of the pedestal and saddle. Furthermore, at each end is a circular plate kept tight up against the pin by a bolt passing through the centre of the pin.



GENERAL SIDE ELEVATION OF THE BRIDGE.

By courtesy of Mr. G. A. Hobson, M.Inst.C.E., designer of the bridge.

The contracts for the construction of the steelwork and for the erection of it at the site were let to the Cleveland Bridge Company of Darlington in May 1903. Exactness to one thirty-second of an inch was specified for some of the members; and to facilitate the assembling of the parts provision was made for pinning them together as erected, prior to riveting. Before the steelwork left the builders' yard it was assembled in sections, so that any inaccuracy might be detected and remedied.

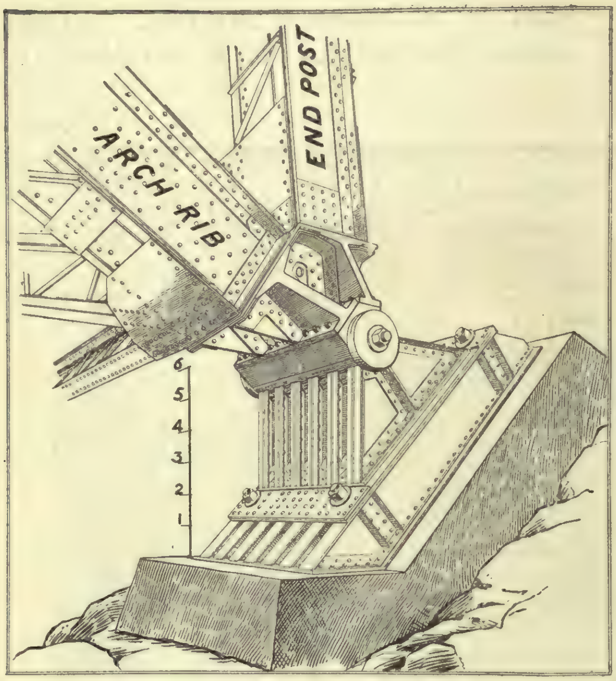
Contract let for the Steelwork.

Delivery of the parts at the Falls was delayed by unforeseen difficulties in railroad construction, owing to which railhead did not reach the Zambesi until May 1904. The first material delivered was that for a cableway to be erected across the gorge near the line of the bridge, to transport to the eastern bank one half of the steelwork, and also rails, sleepers, and plant for the immediate extension of the railway northwards towards Broken Hill.

Erecting a Cableway across the Gorge.

A rocket was shot across, carrying the end of a cord, which served to pull a wire over the gorge. This in turn helped a small steel rope across, to bear a temporary conveyor. Mr. C. Beresford Fox, nephew of Sir Douglas Fox, was the first person to make the apparently perilous passage of the chasm, 400 and more feet above the boiling torrent.

The temporary conveyor transported the materials for the eastern tower of the per-



PERSPECTIVE VIEW OF A MAIN HINGE AND ITS FOUNDATIONS.

By courtesy of Mr. G. A. Hobson, M.Inst.C.E.

manent cableway, for which was provided a rope capable of withstanding a 275-ton strain. As soon as the tower had been erected, one end of the rope was drawn across, passed over the tower, and firmly anchored; the other end being attached to a counter-weighted sheer-legs on the western bank, designed to keep the tension on the cable uniform for all positions of the travelling conveyor.

The Conveyor.

The conveyor itself weighed 5 tons, and was self-moving, picking up current for its motors from a copper trolley wire slung close to it. Its driver, who also operated the hoisting mechanism, was accommodated on a railed platform at one end. Critics asserted that nobody would be found willing to drive the carriage to and fro over the abyss; but this fear was entirely unjustified, and as a matter of fact the aerial journeys became very popular with the employees.

A load of 10 tons could be taken across the gorge by this contrivance, which proved invaluable both to the bridge builders and the railroad constructors. During use the 870-foot steel rope stretched eight inches, but did not show any serious signs of wear until it had carried loads totalling something like 100,000 tons, inclusive of the travelling carriage.

Foundations for the Bridge.

The first item of bridge construction was the placing of the foundations for the four main bearings in excavations previously made by the railway company. Excavating in the north bank was dangerous work, as the face of the cliff was there almost perpendicular, and one of the staff had a narrow escape at this place, being saved from a fatal fall by the branches of a friendly tree. On the south bank operations were easier, but

THE ZAMBESI ELECTRIC CABLEWAY SPANNING THE GORGE.

(*Photo, R. A. Poole.*)

more protracted, as the solid rock had a thick coating of *débris* which must be removed.

About 110 feet below rail-level, on the ledges prepared, the masons laid a thick bed of concrete for the pedestals and bearings, reinforced top and bottom by iron rails. This was allowed to set for several weeks before any weight was placed upon it.

Meanwhile began the construction of the bridge proper. As scaffolding or other direct support from below was out of the question, it was necessary to build the main span out from both banks, on the bracket or cantilever principle, until the two parts of the arch should meet and become self-sustaining.

THE EARLY STAGES OF A CANTILEVER.

(Photo, Cleveland Bridge Company.)

The engineers gave their attention first to the two shore spans, resting at their land ends on abutments built into the rock. The main girders of the trusses were partly supported on temporary timber baulks and trestles, sufficiently strong to bear the additional weight of the jib cranes, which, when the shore spans were completed, lowered the materials for the skewbacks and end posts of the arch. As soon as these were up the shore spans were lowered on to them, and the temporary supports removed.

The next thing was to provide an anchorage at each end to sustain the main span during its cantilever stage. The plan adopted—a novel one—was as follows :—

Some distance back from the edge of the cliff two shafts were sunk to a depth of 30 feet in line with the top of the end posts of the arch. At the bottom they were connected by a short tunnel. A number of wire ropes, specially provided for the purpose, were then attached at one end to an end post, carried down one shaft, through the tunnel, up the other shaft, and affixed to the other end post. Each rope had separate attachments and adjusting apparatus, so that it might be made to bear exactly its fair proportion of the total strain. This gave the cantilever a large amount of Mother Earth—or rather rock—to pull on; but to make safety doubly sure 400 tons of rails were piled on the ground between the two shafts.

Anchoring the Cantilevers.

When once the anchorages were in, the work proceeded rapidly. The cranes, running forwards as the cantilevers grew, lowered the parts of the steelwork to the assemblers, who quickly pinned them at the junctions. At their heels came the riveters with their forges and mechanical closing tools.

To give confidence to the workmen, a huge net was slung under the points where building was in progress. Fortunately it had to catch nothing heavier than bolts and tools, and

THE ARCH RIB COMPLETED. (*Photo, Cleveland Bridge Company.*)

Observe the great safety net stretched under the work.

eventually it was removed, as the men complained that, instead of making them feel more secure, the sight of it caused nervousness. It may be remarked here that the experienced bridge-builder never gets dizzy, and foolhardiness is a greater danger than nervousness. Without hesitation he will walk across a beam only a few inches wide, even when a high wind blows gustily and his foothold is made precarious by ice and snow. The new hand soon gets accustomed to positions the perilousness of which really depends on his nerve. Thus when a "skyscraper" is in its earlier stages he may feel great reluctance to cross a broad plank, but by the time he has helped to build it to a height of 500 feet above the street he experiences no qualms whatever.

The Safety Net and Nervousness.

Progress became more rapid as the cantilevers advanced, and the amount of steelwork in each panel—that is, section of bridge between two upright posts—diminished. The last eight panels at the centre of the arch (out of twenty-six in all) were put together in twenty-six days, and on April 1, 1905—less than six months from the start—the great 3-foot square booms of the arc were joined. The rapidity of the work bears witness to the efficiency of the workmen and the designer, and to the precision with which the parts of the steelwork had been made.

The Cantilevers joined.

In order to give the top chord its proper share of the final strain, a slight gap was left in it until the arch was complete. Hydraulic jacks forced the ends apart to create the required strain, while packing-pieces were in-

THE OPENING OF THE BRIDGE.

The bridge was formally opened to traffic by Professor Darwin on September 12, 1905.

THE VICTORIA FALLS COMPARED AS TO LENGTH WITH OXFORD STREET, AND AS TO HEIGHT WITH ST. PAUL'S CATHEDRAL.

THE GORGE AND THE COMPLETED BRIDGE.

serted and riveted up. Then the jacks were removed, and the anchorage ropes slackened off, allowing the main span to ride free on its four bearings.

The decking of the roadway and the laying of the rails call for no special remark. It is interesting to note, however, that the steelwork received liberal coatings of a gray paint of such a tint that a patch of red dust would show up against it conspicuously by contrast. This colour has the further advantage of harmonizing with the landscape.

Painting the Bridge.

The painting was done by native workmen, who, as Mr. Hobson points out, were ready to follow the white man whithersoever he would give them a lead. "Until the advent of the railway the natives kept clear of the Falls, of which they had a superstitious dread, and for some time afterwards they would not approach them without first flinging up into the air a handful of grass to propitiate the demons of the gorge. But when they found that no harm resulted from a closer association, and that good wages could be earned, they came in their hundreds—some from the remote districts of Central Africa—and proved very valuable workmen. More conservative was an old Barotse chief, who watched the building of the bridge with the greatest interest, but predicted that so slender a construction could not bear the weight of a man. Even when trains began to pass over it he maintained that not its own strength but the finger of God held it up.

The stiffness of the bridge was tested by sending over it a 612-ton train. At the crown the downward deflection was less than an inch with the train moving at 15 miles an hour, and only half an inch with the train at rest.

For several months in the year the bridge is wet perpetually with the spray of the Falls, and for this reason it was of the utmost importance that the designer should make pro-

vision for enabling the painters to get at every part of the steelwork easily, and avoid water-holding and unventilated areas. Rust is one of the deadliest enemies of those who have to deal with steel construction, and if not carefully combated may nullify the finest work.

Now that the bridge is up the critics have been silenced. So far from detracting from the picturesqueness of the scenery, the great parabolic arch serves rather as a standard measured by which the immensity of the chasm comes home to the spectator, who, while admiring the natural features of the great gorge, wonders at the scientific skill that has made a secure path for the locomotive as far above the boiling waters as the cross of St. Paul's is above the busy pavement.

NOTE.—*Some of the illustrations to this article were kindly supplied by the British South Africa Company.*

JOINING UP THE TOP CHORD.

THE DEVELOPMENT OF THE BRIDGE

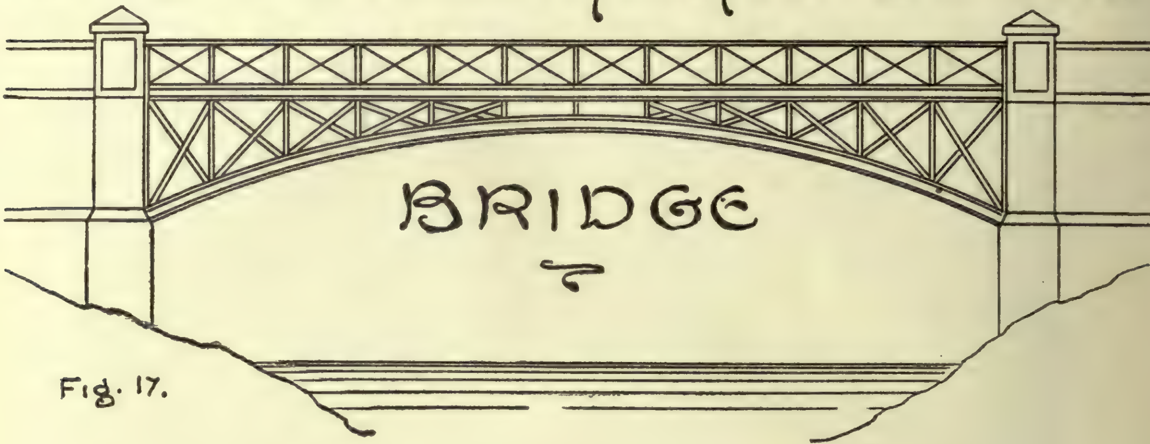


Fig. 17.

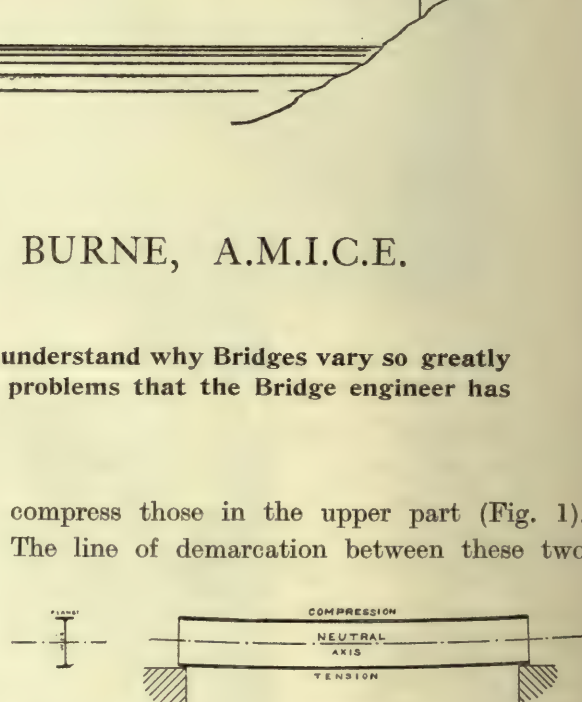
BY E. LANCASTER BURNE, A.M.I.C.E.

This short article will help the reader to understand why Bridges vary so greatly in design, and what are some of the problems that the Bridge engineer has to solve.

THE art of bridge construction was probably the genesis of civil engineering, the principles of the beam and the arch being understood and made use of by the ancients, particularly the Romans, some of whose bridge structures survive to this day. But the greater capacity of iron and steel, combined with the knowledge gained since their introduction, has enabled us to achieve results that would have been impossible in the days of stone and timber.

As the wooden joist was the precursor of the iron girder, a short examination of the effect of a load upon a simple rectangular beam will be a fitting introduction to the subject of the modern steel bridge.

If a beam rest upon supports at each end, and a weight be placed upon it, a bending action is set up which will tend to stretch the fibres in the lower portion of the beam and compress those in the upper part (Fig. 1). The line of demarcation between these two

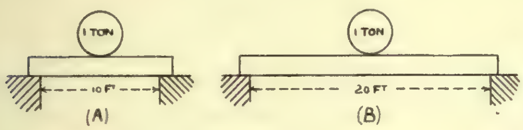


(*Fig. 1.*)

opposite stresses of tension and compression is known as the "neutral axis," and it is evident that the greater the distance of the fibres from the neutral axis, the more advantageously is their strength applied. Given three beams A, B, and C, B having twice the width of A, and C twice the depth, but being in all other respects similar, their relative strengths will be as 1 : 2 : 4, although B and C contain the same amount of material. From this it follows that a solid beam signifies an uneconomical distribution of material. There-

fore in modern joists and girders the metal is concentrated as far as possible in flanges at the extreme top and bottom of the section, in order that the resisting power of the fibres may be applied at an advantageous distance from the neutral axis.

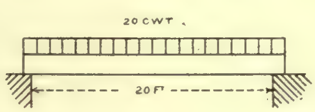
The *carrying power* of a beam also varies inversely with the distance between its supports, for the reason that the "bending moment"—that is, the leverage of the load—is proportionate to the length. Fig. 2 will



(*Fig. 2.*)

help to make this clearer. In case A, the bending moment is equal to half the load acting at a distance of 5 feet from each support (or fulcrum); in case B, the leverage is 10 feet, and therefore the bending effect is doubled.

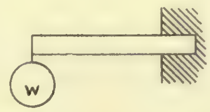
The manner in which a load is *applied* also affects the bending moment. If, for instance, instead of 1 ton concentrated at the centre, as in the above examples, 20 cwt. were distributed equally over the length, as in Fig. 3,



(*Fig. 3.*)

the leverage would be halved, since the average effect of the load equals a 10-cwt. pull exerted at each of two points 5 feet from each abutment instead of at the centre. The stress due to a *distributed* load is consequently only half that imposed by the same load concentrated in the centre of the beam.

Again, the way in which a beam is *supported* affects its carrying capacity. If one end only be fixed and the other free, forming a "cantilever," as in Fig. 4, the bending action of a



(*Fig. 4.*)

weight at the extremity will be *four* times that of a concentrated load upon a beam of the same length, but supported at both ends. This is owing to the fact that the weight is not divided between two supports, while the leverage is doubled. On the other hand, if both ends of a beam be firmly secured instead of merely resting upon supports, each end would act as a cantilever for about one-quarter of the span, and so have the effect of shortening the span.

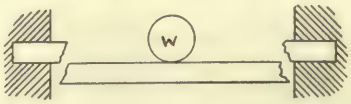
The theory of a "continuous" beam—that is, a beam having three or more points of support, which divide it into two or more "spans"—cannot be stated concisely, because much depends upon the number of spans and the degree and the nature of the loading upon each. Speaking roughly, however, a load upon one span tends to set up a contrary bending action in the span, or spans, adjacent to it, as indicated by Fig. 5, and, in consequence,

(*Fig. 5.*)

partly neutralizes their respective bending stresses. Each span of a continuous beam may be said to be partly composed of two more or less balanced cantilevers, which have the effect of making it stronger than a series of short detached beams of the same section.

Besides producing a bending moment, the pressure of the load upon a beam causes, at

the points of support, a vertical "*shearing*" *stress*, which, unless provided for, would cause

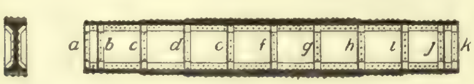


(*Fig. 6.*)

fracture somewhat in the manner illustrated by Fig. 6.

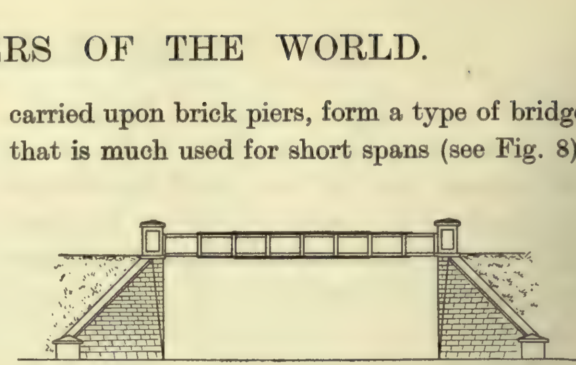
From what has been said in connection with beams, it is evident that the greatest stress in a girder is nearly always due to the bending moment, and occurs at the point where the bending moment is at its maximum. This is normally at the centre of the span, but shifts to other points with the load. In any case, to save dead weight and material, a girder itself should be so proportioned that its strength may increase in the same ratio as the bending moment, and render its resisting power constant throughout its length. This may be accomplished either—(1) by adding to the sectional area of the flanges, or (2) by increasing their distance from the neutral axis towards the centre of the span.

An example of the first method is given in Fig. 7, which shows a parallel "plate" girder.



(*Fig. 7.*)

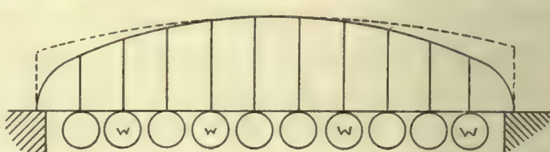
Its strength is gradually increased towards the centre by augmenting the *number of plates* in the top and bottom flanges. Incidentally it may be remarked that the vertical plates *a*, *b*, *c*, etc., are "stiffeners," whose purpose is to prevent sideways buckling of the thin vertical web connecting the flanges. Two or more girders such as this, placed side by side, with decking between them, and their ends carried upon brick piers, form a type of bridge that is much used for short spans (see Fig. 8).



(*Fig. 8.*)

Plate girders are frequently built in a "box" form with two webs.

The second type of girder—namely, that in which the stress on the material is rendered uniform throughout the span by varying its *distance* between flanges and neutral axis—is known as the "parabolic" or "bow-string." Fig. 9 is an outline of such a girder, with a

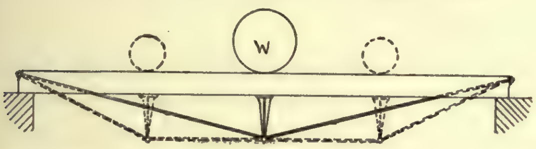


(*Fig. 9.*)

load evenly distributed. The shape has been arrived at by drawing above each weight a vertical line, the length of which is proportional to the bending moment at that point. The curve bounding the upper extremities of the vertical lines is therefore an indication of the depth required to resist *bending*. Owing to the necessity of providing against *shear* at the abutments, the actual outline would approach that shown by the dotted lines. The stresses for other conditions of loading may be determined by similar diagrams. With certain reservations, it may be said that, as the outline so produced represents theoretically the relative depth required at any part of the span, the lines of a well-designed bridge form a "stress diagram," and are, to the educated eye, an expression of its fitness to resist the forces acting upon it. Anything in the nature

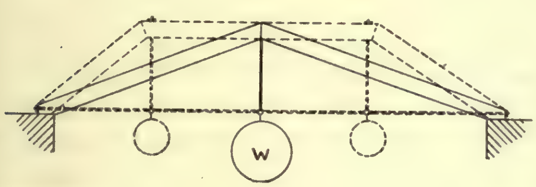
of embellishment is superfluous, and may easily amount to bad taste.

Most large girders consist of open framework, the continuous plate web being replaced by a bracing of "struts" and ties, containing a minimum amount of material, by which the stresses are transmitted to the flanges. Such a framework is sometimes called a "truss." Although the complete structure may be subject to bending moments, the struts and ties are in compression or tension. Fig. 10 is an



(*Fig. 10.*)

example of a trussed beam. From this it is evident that the beam and the strut are in compression and the two ties in tension. If fitted with one strut, the truss is known as a "king" truss; if with two (see dotted lines), as a "queen" truss. Inverting a truss reverses

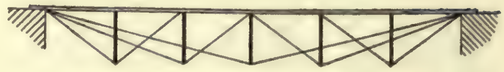


(*Fig. 11.*)

the stresses, and renders necessary a disposition of material, as shown in Fig. 11.

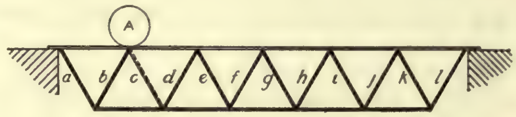
Nearly every braced girder is a development of either the king or queen truss. Thus the "Fink" truss—much used in America—is merely a multiplication of king trusses (Fig. 12).

Fig. 13 is an outline of the "Warren" truss, divided by its bracing into a series of equilateral triangles, the sides of which act as struts or



(*Fig. 12.*)

ties according to the nature and position of the load upon it. The load depends upon the traffic, but nearly always consists of a moving or "live" load more or less concentrated,



(*Fig. 13.*)

added to the distributed dead weight of the structure itself, and to that of the road or railway over it. A dense crowd of people on foot, extending from one end to the other, would constitute a distributed live load; while a heavy vehicle, such as a traction engine, or, in the case of railway bridges, of a locomotive, would be a concentrated live load. Besides the loads just mentioned, allowance has to be made for the stresses due to wind pressure and, usually, for the weight of snow.

A distributed load would place the members *b*, *d*, *f*, *g*, *i*, and *k* in compression, and *a*, *c*, *e*, *h*, *j*, *l* in tension. But suppose a moving concentrated load arrived at *a*, for instance, its effect would be to impose further compression on *b* and compress *c* also. The same would be the case with any other pair, or pairs, of members that the load happened to be over; from which it follows that each diagonal may become alternately a strut or a tie, according to the position of the load. The top flange or "boom" of the truss is, of course, permanently in compression and the bottom boom in tension.

The "lattice" girder (Fig. 14) is virtually a combination of two Warren girders. By pinning the diagonals at their intersection it can be made stiffer than a Warren. A further

(*Fig. 14.*)

combination of two lattice girders gives a "double lattice."

Another much-used type of girder is shown in Fig. 15, the vertical members being struts

(*Fig. 15.*)

and the diagonals ties. In this design the struts are shorter than in the Warren, and are therefore stiffer for a given section.

The remarks that have been made as to the bracing of parallel girders also apply to the "parabolic." The curve of the top (or bottom) boom will, of course, be influenced by the nature of the load; and if the sets of bracings or "panels" are few in number, it will be formed of a series of straight lines, after the manner of an inverted queen truss, instead of being a continuous curve. The varying depth of a curved girder has the effect of shortening the end struts and so saving material, and certainly gives an outline more graceful than that of the parallel type.

A "bow-string" girder (Fig. 16) with a curved top boom is virtually an *arch*, the straight bottom boom forming a tie to prevent the ends from spreading, and taking the place of the massive abutments that perform this function in an open arch. If the load could be applied uniformly to the top member, the diagonal bracing might be dispensed with, and the tie could be removed if the curved boom were placed between two immovable abutments. Fig. 17 is an example of a bridge in which a level roadway is carried upon struts erected upon a steel arch, the whole being made rigid by diagonal bracing.

A *suspension bridge* (Fig. 18) may be considered an arched bridge inverted, the curved

(*Fig. 16.*)

member being in tension instead of compression, and tending to draw the end supports or "anchorages" together, rather than thrust them apart.

In the old form of suspension bridge, with a hanging elastic roadway, the unequal bending action of a rolling load caused undue oscillation. The above example shows a roadway carried on a "stiffening girder" to minimize local deflection. In *girder* bridges variations in

(*Fig. 18.*)

length, due to changes of temperature, can be provided for by allowing the ends to slide on the abutments; but in the case of *arches* and *suspension* bridges the span is fixed and unalterable, so that other methods, such as a hinge admitting of an upward movement in the centre, must be adopted.

A *cantilever bridge* may be likened to a succession of brackets, each arm being composed of a rigid semi-arch or half span of a stiffened suspension bridge (Figs. 19 and 20). It will be noticed that the inshore cantilevers balance those projecting over the water. This plays a most important part in the work of construction, as the work may "grow" riverwards from the piers, thus avoiding the costly "false-

work" or scaffolding that would be required for the erection of a large girder. The ends of each cantilever are joined by a short connecting span or suspended girder.

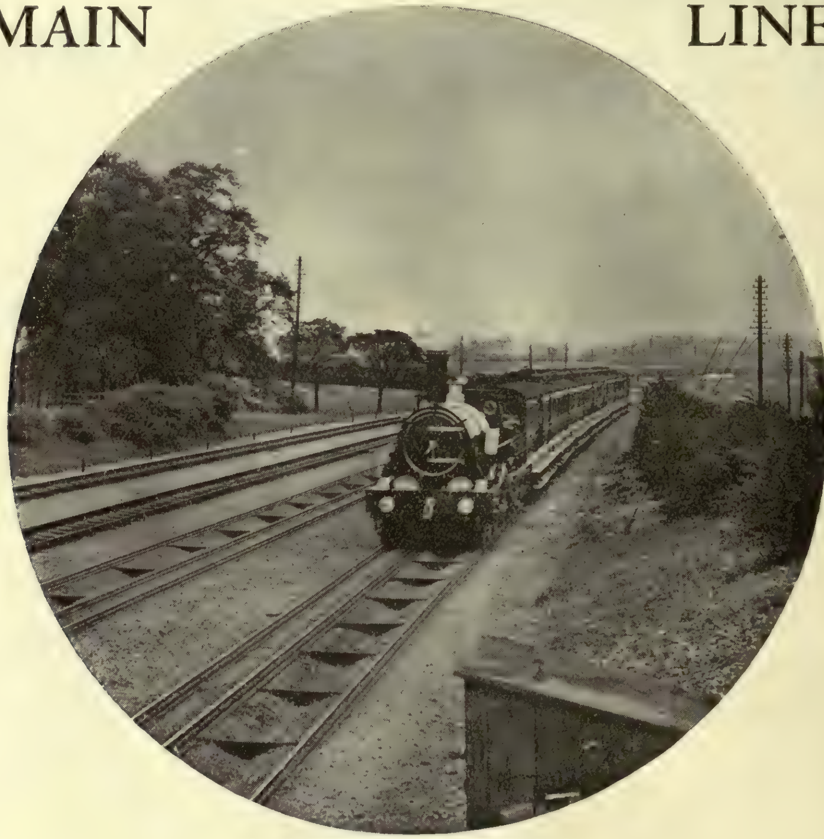
(*Fig. 19.*)

As every bridge requires abutments and, if of more than one span, piers, for which foundations must be found, the choice of the design is largely governed by the nature of the site.

(*Fig. 20.*)

The engineer is invariably expected to provide the cheapest structure that will meet the case efficiently.

THE CONVERSION OF THE GAUGE OF THE GREAT WESTERN RAILWAY MAIN LINE.



A BROAD GAUGE EXPRESS.

BY FELIX J. C. POLE.

A Notable Incident in the History of Railway Engineering.

"IT is proposed to convert the whole of the main line and branches west of Exeter from broad to narrow gauge in the month of May 1892, when it is intended that the alteration shall be carried out between a Friday night and the following Monday, the running of broad gauge vehicles on the line between Paddington and Exeter being thereupon discontinued."

So ran the official announcement by the Great Western Railway that the entire abolition of the broad gauge had been decided upon, and that the work of conversion was to be undertaken with such expedition as to create for all time an engineering feat of the first magnitude—not on account of the difficult character of the work in itself, but from the perfection of engineering and railway organization necessary to accomplish it in the time allotted.

The Broad Gauge.

The master mind of Isambard Kingdom Brunel, the engineer of the Great Western Railway and of many of the once independent lines now forming part of that system, had conceived the idea that the narrow or 4 feet 8½ inches gauge, adopted by George Stephenson for the Stockton and Darlington, London and Birmingham, and other pioneer railways, was altogether too restricted. His clear perception of the great possibilities of the new system of transport caused him to form the opinion that "the whole machine was too small for the work to be done," and he resolved that the Great Western Railway should be on a scale more commensurate with the mass to be moved and the velocity to be attained. On his advice a 7 feet gauge was adopted as being the best from a scientific point of view, and, therefore, more desirable of attainment than uniformity with other lines. Indeed, he considered that the Great Western, having broken ground in an entirely new district and projected branches in various directions, should permanently secure to itself the whole trade of the south-west of England and that of South Wales and the south of Ireland, "not by a forced monopoly which could never long resist the wants of the public, but by such attention to those wants as would render competition unnecessary." But it must be remembered that in the "'thirties" ideas regarding railways were necessarily crude, and by 1844, when the two gauges first met on an important traffic highway, the real disadvantage of a change of gauge became apparent. Moreover, Parliamentary encouragement of competition soon negatived Brunel's theory of railway territory. This fact, and the Report of a Royal Commission in 1844 that, notwithstanding many recognized advantages in the broad gauge, uniformity was so important that, the narrow gauge mileage being seven-eighths of the whole, it should be preferred to the broad, clearly indicated that a standard gauge would ultimately be essential. True, the broad track continued to extend for many years after the Gauge Commissioners had reported, reaching not only to Penzance, but also to Milford Haven, Hereford, Worcester, and even Wolverhampton.

Disadvantage of the Broad Gauge.

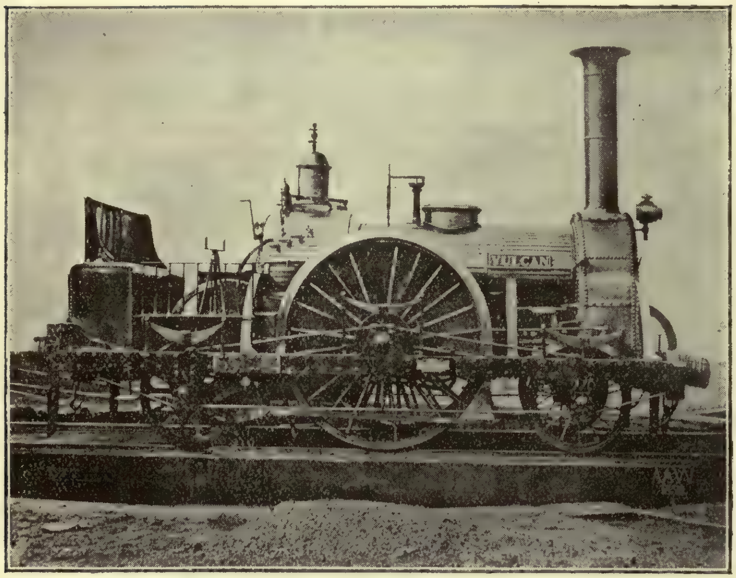
Growth of the Narrow Gauge.

In 1869, however, the first conversion of Great Western lines was undertaken, and thenceforward, partly by "mixing" the gauge—that is, adding a third rail to accommodate both broad and narrow gauge vehicles, and by conversions—the narrow lines were extended throughout the country, until in 1892 Brunel's ideal was confined to some 423 miles of main and branch line between Paddington and Penzance, of which the portions unprovided with a third rail were between Exeter and Truro and certain branches, having an aggregate length of 170½ miles.

Need for Narrowing the Broad Gauge.

The existence of this line involved the railway company in much labour and expense in the transfer of goods and live stock from vehicles of one gauge to those of the other, while passengers from north to west were compelled to change trains, and expenses were increased by the maintenance of the third rail and by providing two classes of rolling stock. The commercial development of the country also demanded such a means of transport as would enable passengers and merchandise to pass without inconvenience to and from all parts; and after much deliberation it was decided in 1891 that the final abolition of the broad gauge should be undertaken during the following year.

Of all previous conversions that had been undertaken, that on the lines in Devon and Cornwall was the most exacting, for the reason that they consisted chiefly of single track,



OLD BROAD GAUGE ENGINE "VULCAN."

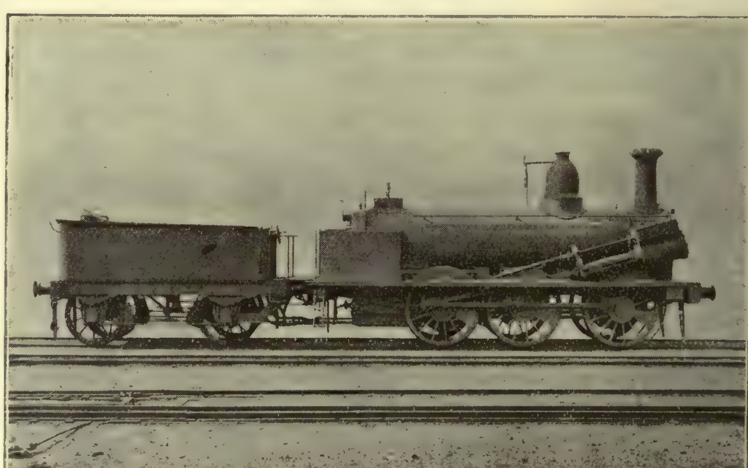
precluding the adoption of the plan followed in the case of the South Wales Railway, for instance, which was to close one of a pair while altering its gauge. The conversion contemplated in the west of England therefore necessitated the entire closing to traffic of a long length of railway, and the problem was how to alter in two days the gauge of lines that had taken as many decades to construct.

The Work to be done.

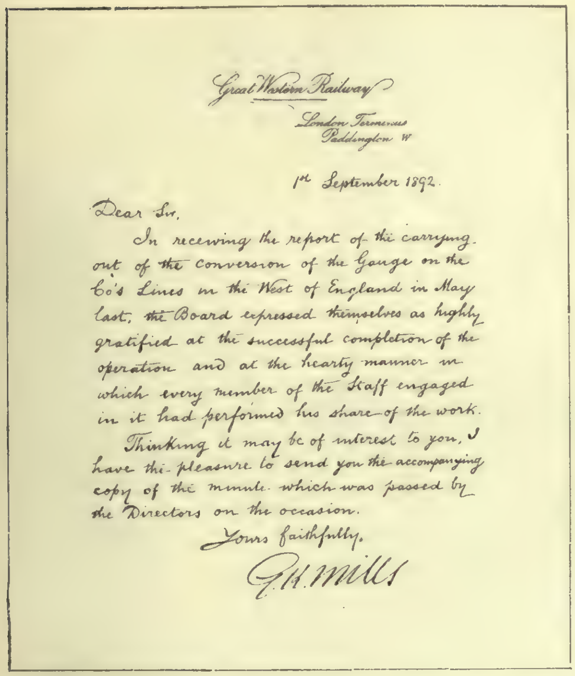
The success of the project was essentially one of perfect organization, and the officials of the Great Western Railway resolved to leave no detail to chance. The main features were—to move all broad gauge rolling stock from the lines to be converted; to subdivide the work and provide sufficient men to carry out the alteration of gauge in the time allowed; and to equip the line with narrow gauge engines and rolling stock for future traffic.

Picture some 200 miles of railway in full working order suddenly denuded of all engines, carriages, and wagons, and some idea will be obtained of the appearance of the Great Western lines between Exeter and Truro on the morning of Saturday, May 21, 1892. Every siding and yard was devoid of vehicles; not a single shunting engine remained. This in itself was by no means the least noteworthy feature of the conversion. During the last few days the broad gauge lines were in use, every vehicle that could possibly be spared was moved to Swindon and placed in the miles of sidings specially provided there, to await conversion to suit the narrow gauge—a work so well arranged that upwards of a dozen coaches were altered in a single morning—or consignment to the scrap heap. Many special trains of engines and vehicles travelled to Swindon—"the broad gauge mortuary," as it was termed—forming a motley procession of old-world stock of all shapes, sizes, designs, and origins, relics of early railway times and

Clearing the Line.



OLD BROAD GAUGE ENGINE "VICTOR."



Great Western Railway
London Terminus
Paddington W

1st September 1892.

Dear Sir,

In receiving the report of the carrying out of the Conversion of the Gauge on the Co's Lines in the West of England in May last, the Board expressed themselves as highly gratified at the successful completion of the operation and at the hearty manner in which every member of the Staff engaged in it had performed his share of the work.

Thinking it may be of interest to you, I have the pleasure to send you the accompanying copy of the minute which was passed by the Directors on the occasion.

Yours faithfully.

G. K. Mills

FACSIMILE LETTER TO PERSONS ENGAGED IN CONVERSION OF GAUGE.

once independent lines. Concurrently with the withdrawal of broad gauge equipment, a supply of narrow gauge engines and vehicles was being concentrated at Exeter and Plymouth, the latter place being reached over the metals of the London and South-Western Railway. Indeed, a few narrow gauge vehicles were even conveyed on broad gauge trucks to remote parts of West Cornwall, in readiness for the recommencement of traffic.

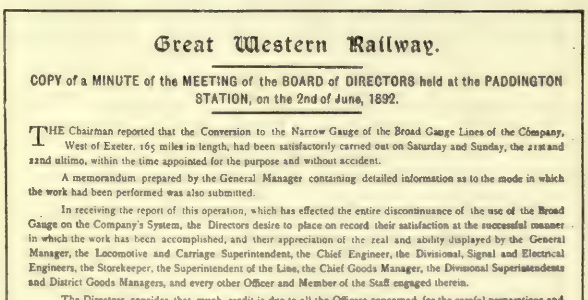
The Last Day of the Broad Gauge.

In due course the last day of broad gauge working arrived, and amid many sighs of regret from the crowds that assembled along the route, the "Cornishman," the 10.15 a.m. from Paddington, made the last broad gauge trip to Penzance. It was drawn by the famous single-wheel engine "Great Britain," and at hundreds of points on the line men, women, and children placed coins of the realm on the railway metals, the flattened discs being preserved as mementos of the broad gauge. At one station in Devonshire the last through trains in each direction met, and the curious spectacle was witnessed of passengers joining hands to the accompaniment of the strains of "Auld Lang Syne."

The Signal to commence Work.

The last broad gauge train to pass between Exeter and Plymouth left the former city at 10.25 p.m., and as this section was largely double track, it was arranged to hand over the "down" line at once for conversion. To effect this, officials travelled with the train, their duty being to deliver to each stationmaster a certificate that it was the last train to pass westward. In turn, the station officials gave written permission to representatives of the engineering department that the work of altering the "down" line might be commenced. The final "up" train left Penzance at 9.10 p.m. It consisted of the vehicles forming the "down" "Cornishman," and called at all stations to Exeter, reaching that place at 4 a.m. on May 21. Its passing was the signal that the line was no longer needed for traffic purposes, and it will be of historic interest to quote the official regulation regarding it. From a copy still preserved we extract this passage: "Inspector Scantlebury must travel by this train, and he

The Last "Up" Broad Gauge Train.



Great Western Railway.

COPY of a MINUTE of the MEETING of the BOARD of DIRECTORS held at the PADDINGTON STATION, on the 2nd of June, 1892.

THE Chairman reported that the Conversion to the Narrow Gauge of the Broad Gauge Lines of the Company, West of Exeter, 165 miles in length, had been satisfactorily carried out on Saturday and Sunday, the 21st and 22nd ultimo, within the time appointed for the purpose and without accident.

A memorandum prepared by the General Manager containing detailed information as to the mode in which the work had been performed was also submitted.

In receiving the report of this operation, which has effected the entire discontinuance of the use of the Broad Gauge on the Company's System, the Directors desire to place on record their satisfaction at the successful manner in which the work has been accomplished, and their appreciation of the zeal and ability displayed by the General Manager, the Locomotive and Carriage Superintendent, the Chief Engineer, the Divisional, Signal and Electrical Engineers, the Storekeeper, the Superintendent of the Line, the Chief Goods Manager, the Divisional Superintendents and District Goods Managers, and every other Officer and Member of the Staff engaged therein.

The Directors consider that much credit is due to all the Officers concerned for the careful preparations and the perfect organization which led to so successful a result, and that every Member of the Staff of the Company, from the highest to the lowest employed on the work, is to be highly commended for the hearty and zealous manner in which he performed the duties allotted to him.

Identified as the Great Western Company has been with the Broad Gauge from the opening of the First Section of the Line in 1837 to the present time, and deriving from it much advantage, the Board came to the conclusion, with great regret, that the time had arrived when the running of Broad Gauge Trains could no longer be continued with benefit to the Company and advantage to the Public, and it is a matter of gratification to the Directors that the alteration, which the force of circumstances had rendered inevitable, should have been effected in so speedy a manner, without accident, and with the minimum of inconvenience to the Public.

G. K. MILLS,
Secretary.

To ....

FACSIMILE OF CARD DISTRIBUTED AMONG EMPLOYEES.

CUTTING THROUGH THE TRANSOMS PREPARATORY TO SHIFTING THE RAILS.

must ascertain from each stationmaster that all broad gauge stock has been worked away, and he must also satisfy himself that the whole of the trains timed to leave the respective junctions in advance have departed. Having done this, he must issue a notice in the following printed form to every stationmaster between Penzance and Exeter: 'This is the last broad gauge train to travel over the line between Penzance and Exeter.'

"On receipt of this notice the stationmasters at the stations between Penzance and Exeter must give a printed notice to the representative of the engineering department, in the following form, that he can take possession of the line: 'This is to certify that the last broad gauge train from Penzance has left this station, and the engineering department can now take possession of the line from the station in the rear up to this station for the purpose of converting the gauge.'"

It is easier to imagine than to describe the feelings of regret with which these "death warrants" were delivered by men, most of whom had grown gray in association with the broad gauge, and who, like many of the local inhabitants, resolutely declined to place faith in the utilitarian narrow track. However, the certificates were given, and between 3.30 and 4 a.m. on Saturday morning, May 21, some 5,000 men commenced the task of abolishing the broad gauge.

"Death Warrants" Issued.

Before describing the operations, it is necessary to digress for a moment in order to relate how this army of labour had been gathered and was organized. All day long on the

previous Thursday special trains crowded with workmen were converging on Devon and Cornwall from all parts of the Great Western system—from Dolgelley and Chester, Wellington and Market Drayton, Milford and remote parts of South Wales, from London and the quiet agricultural districts of

Labour Organization.

SHIFTING THE RAILS.

Gloucester and Wilts. At hundreds of stations these trains embarked about 3,500 workmen (1,500 others were indigenous to Devon and Cornwall), with their permanent-way implements. Even this embarkation was arranged in the most methodical manner. One compartment in four was reserved for tools, while the accommodation for each batch of men was indicated by labels on the carriage windows. The men thus conveyed to the scene of operations were dropped in gangs of sixty all along the track to be converted, and the broad gauge trains in which they had travelled were then hurried away to Swindon. They bivouacked in station waiting-rooms, goods sheds, and tents pitched alongside the railway, these latter being the object of much local attention. Each man provided his own food, but the railway company supplied many tons of oatmeal, which, in the form of thin gruel—oatmeal, water, and sugar—was the staple beverage.

Lodging the Men.

To carry out the work the men were divided into gangs of twenty, each under a ganger. An inspector or foreman was in charge of every three gangs, while controlling the entire work were the chief engineer of the Great Western

Railway, two divisional engineers, and their technical assistants. Each gang was responsible for converting about 1¼ miles of line.

Altering the Gauge.

The permanent way on the Great Western line was as distinctive in character as the gauge. Brunel had so designed his road as to secure a maximum of support under each rail, and instead of the now universal (in the British Isles) cross-sleeper and chair method, he adopted what was known as the "longitudinal" track. This consisted of large timber baulks placed under and running in the same direction as the rails, connected at intervals by cross-timbers termed transoms, and firmly secured with iron tie-bolts.

To alter this type of permanent way involved cutting the transoms, slewing one of the sleepers and the rail upon it to the 4 feet 8½ inches gauge, inserting new tie-bolts, and reballasting the track. In order to reduce these operations to minimum proportions, the ballast had previously been partially removed to admit of one sleeper being brought in towards the other, and alternate transoms had been cut through, the intermediate ones being cut half through. One section of each gang completed the cutting, a second slewed the sleeper into position, and a third bolted together the timbers and packed up the ballast. A witness of the scene has recorded that usually three men cut off the ends of the transoms; then some ten or twelve others, armed with gigantic crowbars, stationed themselves alongside a length of rail, and by a series of rhythmic lifts and heaves moved the longitudinal sleepers, with the rails upon them, some 6 or 8 inches, continuing this to the end of their stretch of line. Afterwards they returned and repeated the operation, closing up the sleepers another few inches,

BOLTING UP THE TRANSOMS AFTER CONVERSION.

Methodical Work.

A DIFFICULT PIECE OF WORK—ALTERING THE POINTS AT PLYMOUTH.

and finally, with a third lift, placed the two rails at the proper narrow gauge distance apart.

This was naturally quite a simple expedient on straight stretches of line. Indeed, by midday on the Saturday long lengths were ready for the tie-rods that were to keep the rails true to gauge, and for the final packing of the ballast. But where the track was curved the alteration was a more difficult matter. The outer or inner rail, as the case might be, in a curved broad gauge line was longer or shorter than would be the case on a narrow gauge, as the two gauges gave arcs of circles described at different radii; hence much cutting, exact fitting, and testing were necessary. This was a feature of a great part of the work, as the railway through South Devon and Cornwall is notorious for its many curves. The men, therefore, were constantly cutting a piece from one rail, or substituting a longer length for another. Now, cutting a rail in a workshop with every facility for doing so is simple enough, but on the stretch of line undergoing conversion the work had to be done with cold chisel and sledge-hammer—a very different matter. To cut a single rail occupied several men for half an hour or longer—quite a considerable period, having regard to the time in which the entire work had to be done—and unless the measurement had been most carefully made, the task of cutting might be completed only to find that an extra inch must be removed.

Difficulties on Curves.

Cutting the Rails.

In one or two places, where the line had been relaid previously, cross-sleepers had been introduced, chairs being provided at the narrow width. On these lengths the rail had merely to be transferred from one set of chairs to another and the sleeper ends cut off; but at stations, particularly large ones, the work was of a most exacting character, owing done on the following day being to complete the laying in of some of the fittings, and to finally ballast, test, and adjust the line. For testing and consolidating the track a number of narrow gauge engines were employed to pass to and fro over the several sections, which, one by one, were certified complete and ready for the passage of traffic.

BROAD GAUGE LOCOMOTIVES IN THE "MORTUARY" AT SWINDON, WAITING TO BE BROKEN UP.

Over seventy engines are included in this photograph.

to the number of lines and the complicated blocks to be laid in. At Plymouth and some other large centres the broad gauge lines were entirely swept away, and new sets of switches and crossings inserted; but whichever expedient was adopted, the work proceeded apace, and by Saturday night the gauge was narrowed practically throughout and the sleepers tied, all that remained to be

Testing the Line.

The entire work was finished well within the appointed time, thanks to the fine weather that prevailed and the completeness of the arrangements; and the Sunday night mail train from Paddington to Penzance, after traversing the London and South-Western Railway from Exeter to Plymouth, continued its journey to Penzance over the newly-altered track. On Mon-

The Gauge converted in Thirty Hours.

day, May 23, the usual service of trains was in operation, the conversion having been carried out in about thirty hours, without any accident whatever, and with a minimum of inconvenience to the travelling public —even the mails being conveyed by Great Western steamers between Plymouth, Fowey, and Falmouth, and distributed thence by special road vehicles.

The cost of the alteration of lines, rolling stock, and incidental improvements exceeded £1,000,000; but a barrier to free transportation had been removed, and the way paved for doubling the line and providing the "Cornish Riviera Express" and other notable services, for which the Great Western line has since become famous. Many still believe that the broad gauge would have been the remedy for some difficulties that to-day confront railway engineers, mechanical and civil; but standardization was essential. Brunel's line was gone; its results remain. It had demonstrated the advantages of rapid transit, and indicated what the locomotive could do. Had it not been introduced, we might even to-day be jogging over the country in "express" trains timed at from thirty to forty miles an hour, instead of at the "mile-a-minute" standard set up by the broad gauge.

OLD BROAD GAUGE ROLLING STOCK AT SWINDON.

Though the locomotive designer has taken full advantage of the dimensions permitted by the narrow gauge, and has, notably in America, produced remarkably powerful engines, it is now a matter for regret that George Stephen-

son and other railway pioneers should have selected for the iron horse the gauge of the stage-coach which it supplanted. An increase by a few inches in the gauge would, if it were feasible, be of the utmost help for economical running and rapid transit. But bridges and tunnels suited to the 4 feet 8½ inches gauge are already in existence, and the cost of altering them would be so enormous as to be quite prohibitive. Therefore, while railways of the present type endure, the gauge for our trunk lines must remain what it is. In this country we are additionally handicapped by the restricted loading gauge—this also imposed by the tunnels—which compels us to keep our rolling stock within narrower limits than prevail in the United States and elsewhere. Had Brunel appeared on the scene a few decades sooner, a more generous gauge might have been adopted generally in the British Isles. Even if it had erred on the broad side in the first instance, the error could have been corrected; whereas, as things stand, any alteration is impossible.

NOTE.—*Most of the photographs illustrating this article were kindly supplied by the Great Western Railway Company.*

AN EARLY BROAD GAUGE ENGINE LEAVING BOX TUNNEL.

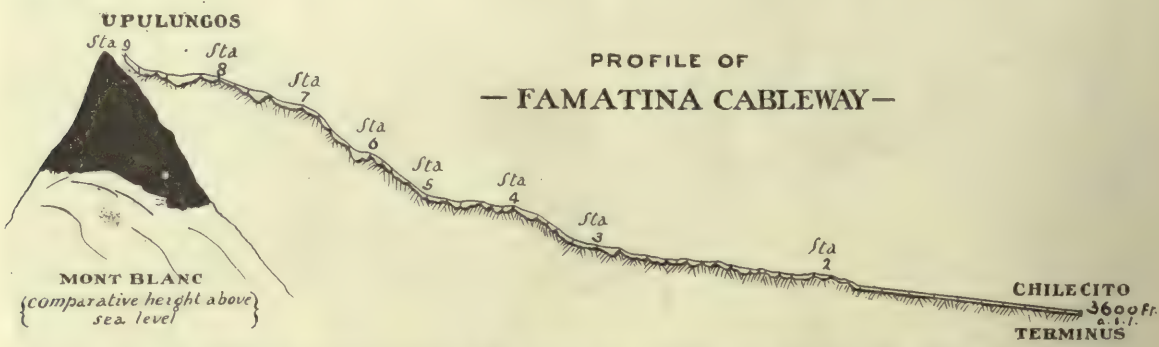
THE UPULUNGOS MINES—SITE OF THE UPPER TERMINAL.

A WONDERFUL AERIAL ROPEWAY IN THE ANDES.

A Brief Description of the Longest and Loftiest Cableway in the World.

Mining in Argentina.

EVER since the conquest of Peru by the dauntless Pizarro and his Spaniards, the Andes have been famous as a Tom Tiddler's ground, in which fortunate people may find gold, silver, copper, and other valuable metallic ores. Peru and Chili have had their turn. Attention is now being given to the Argentine Cordilleras, where for many years mining has been carried on in a rough-and-ready fashion by miners of the hardiest kind, and where will be some of the greatest mining centres of the future. In the northern districts of the country, on the eastern slopes of the great mountain range, there exist great deposits of iron, gold, silver, and copper ores. Railways have been pushed towards them, and now you may travel comfortably 800 miles north and west from the fine port of Buenos Aires to the



Profile of Cableway, showing height of Mont Blanc as compared with that of the Upper Terminal

little town of Chilecito, which lies on the foot-hills, within 300 miles of the Pacific, and about 3,600 feet above sea-level. To the west of Chilecito rise the frowning, seamed Cordilleras, a chaos of mountain and ravine. Far up in these, at an altitude approaching that of the summit of Mont Blanc, are the valuable Famatina copper mines, which have been worked for many years by natives on the principle of picking out the plums from the pudding. The only means of communication between Chilecito and the mines was, till recently, a mule track of the roughest and most precipitous character imaginable, passable for only six months out of the twelve, as winter storms cover it with deep drifts of snow. Though the distance from the town to the mines is but 22 miles as the crow flies, the difference in elevation—some 12,500 feet—compelled travellers to take a roundabout way. The ascent occupied, under favourable circumstances, two and a half days, the efforts of man and beast growing more painful as the altitude increased and the air became more highly rarefied. Arrived at the mine, the muleteer rested a day before loading up his mules with ore for the descent, which was as tedious and difficult as the upward journey. It is not surprising therefore that transport of ore from the mines to the smelters cost about 50s. per ton.

The Famatina Mines.

Costly Transport of Ore.

When the railway reached Chilecito an English company was formed to take over the mines from the Government, and work

THE OLD MULE TRACK.

them in a more up-to-date manner. One condition imposed by the company was that the Government should establish easy communication between the mines and Chilecito. A glance at the illustration on page 123 will suffice to show the extremely difficult nature of the intervening country.

A Cableway projected.

The system adopted provided for two fixed carrying ropes—an "up" and a "down" line—on which the cars would run, suspended from wheeled carriages. Motion was to be transmitted to the cars through endless hauling ropes. The cableway was designed to transport 40 tons per hour down-

The System adopted.

THE OLD MULE TRACK TO THE MINE.

The cost of an ordinary or even of a rack railway would have been prohibitive, so it was decided to establish an aerial railway, some 21½ miles long, on an almost straight line between the two terminals. The contract for building the cableway fell to Messrs. Adolph Bleichert and Co. of Leipzig, to whom the writer is much indebted for most of the pictures illustrating this account of the cableway, and for much of the following information.

hill, and 4 tons per hour uphill, the individual loads, cars included, being limited to about half a ton.

The contractors had to face several very difficult problems. In the first place, the cableway was to be one of unprecedented length, and this necessitated dividing it into eight separate sections, each having its own hauling rope. At the seven intermediate stations arrangements had to be made for uncoupling the cars from the hauling rope of

one section and coupling them up to that of the next section in the series. The uninitiated reader may suppose that, with a difference of level between the two terminals of over 12,500 feet, the force of gravity would suffice to work the traffic both ways, the descending laden cars hauling up the empty cars. On a short line this method is often employed. But here it had to be combined with the use of a steam-engine, owing to the variation in the weight of the ascending load of men, water, timber, machinery, and other supplies.

RAISING A COMPLETE TOWER ON ITS BASE.

The actual construction of a cableway in the rough, desolate Cordilleras also presented many difficulties. An ordinary railway feeds itself as it grows, material being transported over the completed part of the track for the length ahead. With this cableway the case was different, as a whole section had to be finished before anything could be moved over it, and therefore some independent form of transport was required. In addition to human carriers, 90 donkeys and 1,000 mules—these last supplied by the Argentine Artillery Corps—were employed. Parts of the iron structural work for the towers to carry the cables were limited to about 330 lbs., a full load for a mule. Units which exceeded this weight had to be moved by gangs of men.

Difficulty of Transporting Material.

The grademen led the way, to dig and blast cuttings through the sharp mountain peaks to give a sufficiently large radius for the ropes. From one of these cuttings over 7,000 cubic yards of rock had to be shifted; and at one point it was necessary to drive a tunnel 164 yards long by $13\frac{1}{2}$ feet high and $14\frac{3}{4}$ feet wide through the peak of a very pointed hill. After the navvies came the masons, who built up the massive piers to carry the towers; and behind them followed the tower erectors. Some of the towers were short enough to be assembled horizontally and tilted up bodily into their final positions. But the taller structures, ranging up to 140 feet in height, were built up on their bases story by story. As soon as all the towers

Building the Towers.

of a section were completed, the ropes for that section were brought along; and it may be noted that the conveyance of the ropes was the most troublesome job of all, because these items of the outfit could not be subdivided. Some of the lengths weighed two tons or more. The ropes were wound on large drums, after the manner of electric cables, for transport from the factory to Chilecito. When the time came to use a rope it was unwound and paid out on the line of the cableway by large gangs of men, a certain weight being apportioned to each man. The drum being empty at last, the procession took its slow and snake-like way uphill, until the rope reached its destination. There the rope was raised on to the towers, made fast at one end, and strained to the pre-determined curve. This method of transport cost a lot of money—about £2 per mile—so that where possible the ropes were forwarded over the completed sections, attached in coils to a number of car-hangers.

Transporting the Ropes.

Some 1,200 men were employed on the work. The hours of labour and rate of wages varied with the altitude. On the lower sections some ten to twelve hours made a normal working day; but in the mountains, where respiration was more difficult and every movement of the body more exhausting, an eight-hour day was the rule. On the highest sections of all the summer temperature seldom rises above 5° Centigrade, and in winter the thermometer

Intense Cold at High Altitudes.

THE COUNTRY TO BE COVERED BY THE CABLEWAY.

The route is indicated by a straight line; the circles show the sites of the stations.

stands far below zero. Icy winds, rising at sunset, make the open air unendurable after darkness sets in. We find, therefore, that the workmen were duly compensated for extra hardship. Thus, at 3,600 feet a mason received 6s. 4d. a day, but at an elevation of 14,000 feet his pay increased to 15s. for a working day of from five to eight hours only.

As the sides of the mountain are as barren as the sandy wastes of the Sahara, the workmen depended for supplies entirely on the ropeway completed behind them, which brought up also all the materials for the stations and engines, and the thousand and one articles required in a mining town. Yet in spite of the many physical difficulties that the motley gangs of labourers had to face, the cableway was finished in fourteen months from the start, which was made in December 1903.

CARRYING A 2,000-FOOT LENGTH OF ROPE UP THE MOUNTAIN.

We may now give some attention to the gradients of the cableway. The line com-

mences near the railway terminus at Chilecito, and runs in a straight line up a moderate incline for five and a half miles to the first intermediate station. The second section is also comparatively easy going, although the inequalities in the ground already begin to be formidable. After station 3 the serious climbing commences, and the gradients become more and more severe until station 7 is reached. Between stations 4 and 5 the ropeway crosses the so-called "Seven Heights," and passes through the tunnel mentioned on a previous page. At the upper end of the tunnel is a span of 1,770 feet, crossing the Cerro Negro at a dizzy height. After passing station 5 the cableway climbs the slopes on a terrific gradient, rising 29 feet in every 100. The next section is even steeper, and includes spans of 2,177 and 1,881 feet. The rise then becomes more gentle ; but the last two sections

SPAN ON ONE OF THE UPPER SECTIONS : 120-FT. TOWER IN FOREGROUND.

Gradients of the Cableway.

THE CABLEWAY IN WINTER.

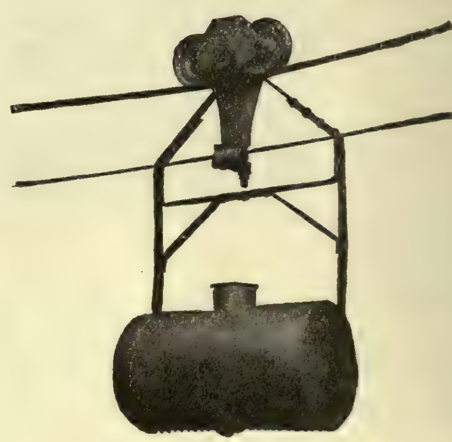
have the longest spans of all, each over half a mile long. Between stations 3 and 9 the ropes climb 10,000 feet in about 12 miles. In four hours a traveller on the cableway is raised from a point some 3,500 feet above sea-level, where the sun shines hotly, to an elevation considerably greater than that of Mont Blanc, and finds that in this short time he has exchanged summer for winter. To the unseasoned this rapid ascent brings the *soroche*, or mountain sickness, which also comes to passengers on the wonderful Oroya-Lima Railway in Peru.

When a day's working commences, the first cars dispatched from the upper terminal are only partly filled, and the loads are increased as soon as cars are moving upwards, either empty or bearing supplies for the staff of the cableway and the miners. When a car reaches a station, it lets go of the hauling rope of the last section, is pushed across a short level stretch, and attached to the hauling rope of the section below. When at last it arrives at the lower terminal it runs over an automatic weight recorder, which registers the load, and is emptied into one of a number of hoppers. Then it starts on the upward journey, and so travels up and down all day long.

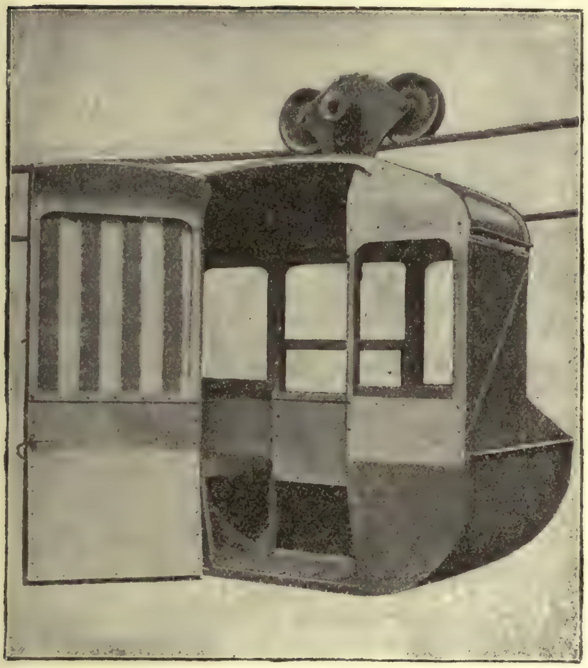
Working the Cableway.

One of the most interesting mechanical features of the cableway is the automatic gripping device for giving a car a hold on the hauling ropes. The jaws of the grips are actuated by the weight of the car itself. The steeper the incline and the greater the pull, the tighter do the jaws cling to the

Automatic Rope-gripping Device.



A WATER-CAR.



A PASSENGER CAR.

rope. Furthermore, when a car enters a section it takes hold gradually, so as not to cause any sudden strain.

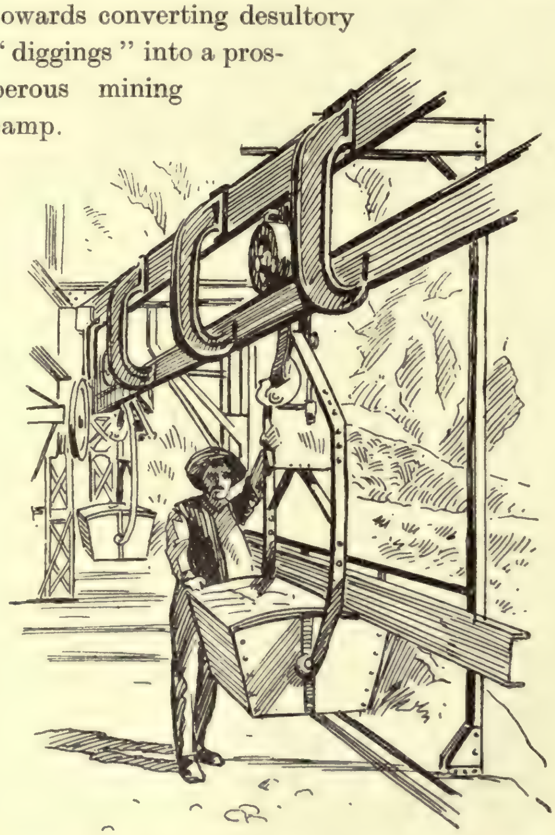
The heavy carrying ropes are lubricated by a special car, having on it a cask of oil and a pump. The pump, driven by the wheels of the carriage, squirts oil on to the wheels for delivery to the ropes, over which it is spread evenly by brushes. To preserve the hauling ropes, tanks of oil are provided on the stations, and the ropes, as they travel, pass over rollers half submerged in these tanks.

Lubricating the Ropes.

The total rolling stock on the cableway numbers 640 cars, including vehicles for special purposes. At every station is a small shop, in which minor repairs may be effected, and at the Upulungos terminal has been established a very efficient repairing works equipped with lathes, machine tools, and all other necessary plant. The same is the case at Chilecito, as it is of the utmost importance that in so remote a region the outfit should be as independent as possible of outside resources. The line is worked on much the same principles as ordinary railways. At each station is a stationmaster, a telephone operator, and employees, whose duty it is to patrol the line and see that everything is in proper working order. The telephone wires run parallel to the track on separate posts of iron placed about 110 yards apart. By means of portable telephonic apparatus workmen are able to get into communication with the nearest station, and report quickly any defect discovered.

As an engineering work the construction of the Famatina Cableway may be reckoned no mean achievement. When employed to its full capacity the line will transport ore from mine to smelter for little more than a fifth of the sum charged per ton by the muleteer, and so will do much towards converting desultory "diggings" into a prosperous mining camp.

Effects of the Cableway.



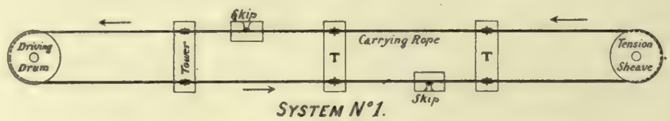
CARRIER AND SKIP PASSING THROUGH A STATION.

A NOTE ON THE VARIOUS SYSTEMS OF CABLEWAYS.

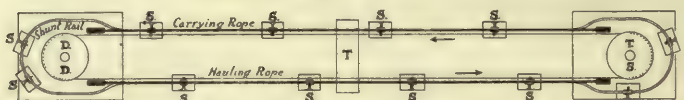
THE diagrams appended will serve to inform the reader as to the four chief systems of cableways commonly used to meet various conditions of haulage. In each case the rope which carries the load is indicated by a thick line, whereas a finer line stands for the hauling rope. The letters S S = skips, attached to carriers; T T = the towers supporting the ropes; D D = the drums communicating motion to a moving rope; T S = a tension sheave by which a moving rope is kept at the proper tension.

System 1.—An endless running rope with carriers hanging therefrom. The carriers are either (*a*) rigidly fixed to the rope, or (*b*) move with it by frictional contact. The first sub-system is suitable for moderate loads and for gradients not exceeding 1 in 3; the second for moderate loads and very severe gradients.

System 2.—Two fixed ropes to act as rails, and a separate endless hauling rope travelling always in the same direction to move the carriers. This type, of which the Famatina cableway just described is a notable example, is generally used for very long spans over which loads ranging up to 5 tons have to be transported. The carriers travel in one direction on the one rope, and return over the other rope, the transference being made by means of a shunting rail.

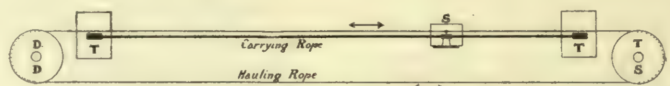


SYSTEM N°1.

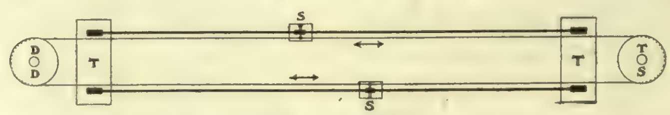


SYSTEM N°2.

System 3.—A single carrying rope, over which a single carrier is drawn to and fro by an endless hauling rope. The double-headed arrows indicate that the direction of the hauling rope is reversed between every two trips of the carrier. This system is most suitable in situations where very heavy individual loads have to be moved over very steep, long spans.



SYSTEM N°3.



SYSTEM N°4.

System 4 is practically a duplication of No. 3, for use with two carriers, under similar conditions. The descending load may be utilized (as also in Systems 1 and 2) to draw up a somewhat lighter load. Spans of 1,500 yards are used in this system.

[*We are much indebted to Messrs. Bullivant and Company of 72 Mark Lane, London, for the above information.*]

A TRAIN CROSSING THE BAY OF FLORIDA.

THE FLORIDA EAST COAST RAILWAY EXTENSION.

An Account of the Construction of a unique Railway which for many miles runs over the open waters of the Bay of Florida.

TO travel from New York to Havana, the capital of Cuba, by train without change of cars is now a possibility, or rather probably will be by the time this article is in the reader's hands. This is due to the construction of the Florida East Coast Railway extension, by which trains will run direct to Key West, and there be transferred to large ferry-boats, and carried across the sea to Havana, some 90 miles distant. To understand what this task has meant to the railway builder, a glance at the accompanying map of the district is necessary. Key West, an important naval station belonging to the United States Government, is situated on a small island of that name, some 156 miles by boat from Miami, a small port on the mainland of Florida. Between Key West and Miami there runs a stretch of coral islands, called "keys." The railway has been carried to Key West by using these islands as stepping-stones.

New York to Havana by Train.

Some four years ago Mr. Henry M. Flagler decided to connect this outlying post of the United States with the mainland by rail. Mr. Flagler is a millionaire, often referred to as the "King of Florida," who has done more than any other man to develop this country, and rightly believes that there is nothing like a railway for this purpose. He has certainly had experience in this direction, there being over 600 miles of iron road in Florida which have sprung into existence at his bidding. But his latest scheme was a decidedly original one. It offered problems which the railway builder had never been called upon to face. It virtually meant the constructing of a railway out to sea, for of the 156 miles of track which runs between Miami, on the mainland, and Key West, fully 75 miles lie over water, and a considerable portion over the sea itself.

The first question the engineers had to answer was how far down from Miami the track could be laid on the mainland before jumping off on to the keys. To ascertain this, engineering parties spent months at a time in the Everglades carrying out surveys. The Everglades may be likened to a large shallow lake, enclosing thousands of islets covered with dense thickets, and containing

Difficulties of Surveying.

great numbers of alligators. These brave men suffered terrible hardships in this inhospitable region. One party had to be rescued by a relief expedition, and was found on the verge of starvation. In the end it was decided to run the line down to Homestead, and from

CLEARING FOR VIADUCT THROUGH COCOANUT GROVES ON LONG KEY.

there across the Everglades to Water's Edge or Land's End, the distance between Homestead and Water's Edge being some 17 miles. At this point the road becomes truly marine, or, more exactly, amphibious, reaching its destination, Key West, by crossing forty-seven islands. The channels between these vary in width from a few hundred yards to several miles, with a depth of water from a few feet to over forty feet. The road is carried over these gaps on embankments and viaducts of concrete built up from the ocean bottom. Surveying in the keys was particularly difficult. Most of the work had to be done afloat, and some of the engineers were lost among the hundreds of islets for days at a time. Tall towers had to be built for sighting the instruments on account of the distance between the islands.

The first 28 miles of line south of Miami were comparatively easy. At this point the Everglades are entered, and the next 17 miles, down to Water's Edge, are virtually through a heavy mangrove swamp, and it was here that the first difficulties were encountered. An embankment was thrown up for the track with the help of specially-constructed dredges. Before these could be set to work, however, the engineers had to dig out a channel on each side of the route. Down these channels the dredges, navigable in 2½ feet of water, made their way, using the material excavated for building up the railway embankment. They were continually hampered and delayed in their task by the rock, which came so near the surface as to necessitate the construction of locks to float the machines over them. Then had to be filled two arms of a large bay—Jewfish Creek—over which the railway is carried. The filling of these arms made it necessary for the engineers to form an artificial outlet to the creek. So the line continues right down to the shore, and reaches, by means of a handsome steel drawbridge, the first of the keys—Key Largo,

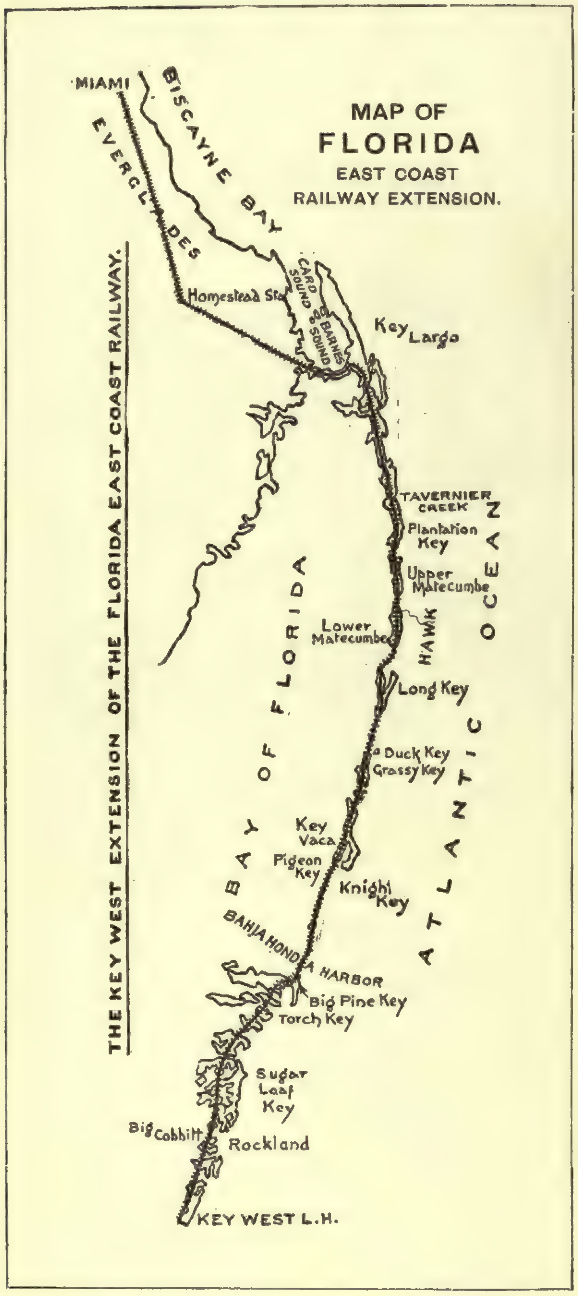
Dredging in the Swamps.

ONE OF THE FILLS ACROSS A SEA BREAK.

the largest of the islands. The track here continues for some 16 miles, its embankment being built up entirely of coraline limestone, as is every one of the railway embankments crossing the various keys. At the south-western end of Key Largo, Tavernier Creek, which separates it from Plantation Key, is crossed by a steel bridge with concrete piers and abutments. Completely obstructing the line of grade on Key Largo was found an inland lake not encountered in the preliminary surveys, half a mile wide and six feet deep, the bottom of which was wholly composed of peat. In order to displace this peat and sink a more stable foundation for the embankment, two dredges worked constantly for fifteen months.

On the first Island.

By this time an army of 2,800 men had been collected and distributed over the route, there being no less than thirty construction camps. Much nonsense appeared in certain sections of the press as to the hardships the labourers were called upon to endure. Their work was certainly not pleasant, but the company did everything possible to make their surroundings as comfortable as circumstances would permit. No man was kept at work against his will. After a few days' stay on the keys, hundreds threw up their jobs and went north. The fact is, much difficulty was experienced in securing the services of reliable workmen. This was no doubt due to the fact that the Panama Canal had snapped up the best of the available supply. The result was that hundreds of tough customers were found in the camps, and strict rules had to be enforced to maintain law and order. Intoxicating drink of any kind was debarred, and the strictest measures were employed to prevent the men from getting hold of it in any way. Occasionally a small boat would try to escape the vigilance of the engineers and the revenue cutters, but it was usually captured sooner or later by the revenue



men and promptly scuttled then and there. The majority of the men were willing to have this rule enforced, as it gave them an opportunity to save money. Ordinary labourers received from £7 to £8 a month; sub-foremen or gang foremen, £12; foremen, £15 a month; and engineers were paid from £35 a month upwards. All had their board and lodgings free. It cost £1,600 a week to feed this army of workmen.

The coloured men lived in tents on the keys, and did their own cooking, their food being supplied to them by the company. The white labourers, who numbered four-fifths of the staff, lived in what were known as quarter-boats, virtually floating hotels, with bunks banked one above the other. The bunks, windows, and doors were screened with mosquito netting. The mosquitoes on the keys are very large and fierce, but were seldom troublesome in the daytime, though veritable pests at night. The men put in ten hours' work a day, and none at all on Sundays. Their leisure hours were spent in lounging about the houseboats or strolling along the keys and bathing. At Miami the company established a large hospital for the benefit of the workmen, and some 4,000 cases were attended to here.

Workmen's Floating Hotels.

As one engineer summed it up, "It was bound to be a web-footed proposition from start to finish." The line was virtually built from boats, necessitating the services of a fleet of very miscellaneous and costly craft. For use along the keys alone there were requisitioned three tugs, eight stern-wheel steamers of the Mississippi River type, thirty gasolene launches, fourteen houseboats each with accommodation for 144 men, eight workboats fitted with derricks and concrete mixers, three floating pile-drivers, one floating machine shop, and over one hundred barges and lighters.

Railway built from Boats.

Briefly, the leading engineering features of this railway are as follows :—

Distances.

From Miami to Homestead	28 miles.
From Homestead to Water's Edge	17 miles.
From Water's Edge to Knight's Key	64 miles.
From Knight's Key to Key West	47 miles.
	156 miles.

17 miles run through the Everglades.
There are 23 miles of embankment in the open sea.
There are 6 miles of viaduct in the open sea.
Longest viaduct, 2 miles.
Longest gap between islands, 6 miles.
Largest island crossed, 16 miles long.
Number of islands crossed, 47.
Bridges in the open sea, 10.

From Key Largo, the first of the islands tapped by the railway, to Long Key, the line is carried over the sea-gaps between the keys by embankments built up from the ocean bottom. Then we reach the first of the four arched viaducts. If the engineers had had their way, they would have connected the whole of the forty-seven islands over which the line passes by massive ramparts. But the Government at Washington became uneasy at the notion of a solid wall stretching from the mainland to Key West, fearing that it might shut off the tidal flow, and so disturb the aquatic equilibrium of the Bay of Florida. Therefore the builders were respectfully informed that they must include a certain number of bridges by way of openings in their embankments, in order that the immemorial habits of the tide in this part of the world should not be hampered.

The Viaducts.

To the lay mind these viaducts are the most picturesque part of the whole undertaking. There are four of them, aggregating 6 miles in length. They extend from Long Key to Grassy Key, 10,500 feet; across Knight's Key Channel, 7,300 feet; across Moser Key Channel, 7,800 feet; and across Bahia Honda Channel, 4,950 feet. We get some idea of what it meant to erect these viaducts in the open sea when we learn that that at Long Key consists of no fewer than 186 arches, and is 2 miles in length. In the erection of this particular viaduct 286,000 barrels of cement, 177,000 cubic yards of crushed rock, 106,000 cubic yards of sand, 612,000 lineal feet of piling, 5,700 tons of reinforcing rods, and 2,600,000 feet of dressed lumber were used. A large fleet of boats had to be chartered to convey this material to the scene of operations. The crushed rock alone filled eighty tramp steamers. Where the water was shallow special rafts had to be constructed to carry the necessary erecting plant, ordinary vessels being used in the deeper water.

Bridges into the Sea.

In the construction of these concrete arches

PLACING COFFER-DAMS IN POSITION FOR ARCH FOUNDATIONS.

the generally adopted method of railway bridge building was employed. Pier piles and arch-bent piles were first sunk, and the coffer-dams lowered and pumped out. A seat of concrete was then placed at the bottom of the coffer-dam, and upon this the concrete construction of the pier rests. Twisted

Building the Viaducts.

CONSTRUCTING A PIER "FORM" IN A COFFER-DAM.

steel reinforcing rods were then placed in position, the upper ends protruding from the top of the concrete pier. The arch-bent piles were then ready to receive the arch forms. When the erection of the spandrel wall forms was completed on each side of the arch, the reinforcing rods were joined by means of heavy wire to those protruding from the pier, and the reinforcing continued inside the spandrel wall in the ring of the arch. The next step was to fill the forms and spandrel walls with concrete, and tamp it into position; which done, the whole was allowed twenty-eight days to set. The completion of the spandrel wall was followed by the dislodgment of the arch forms from the arch-bent piles. These were floated away on barges, and used over again as many times as the condition of their timbers warranted.

When some ninety of the arches of the Long Key viaduct had been completed, a hurricane that swooped down upon the keys not only tested the work of the engineers to the utmost, but made havoc in the ranks of the men. The finished arches stood the test well, but hundreds of pier forms and costly wooden frameworks were washed out to sea and lost. The camps on the islands were blown down, vessel after vessel was torn from her moorings and swept out to sea, and much valuable floating equipment lost.

An American writer who visited the works

after this storm thus describes the fate of those who failed to escape to land when their boats broke loose:—"One of the quarter-boats, *Number Four*, was torn from its moorings at Long Key before the 145 men aboard could try to get ashore. Shortly before daylight it drove across the Hawk Channel in a

Lives lost by Storms.

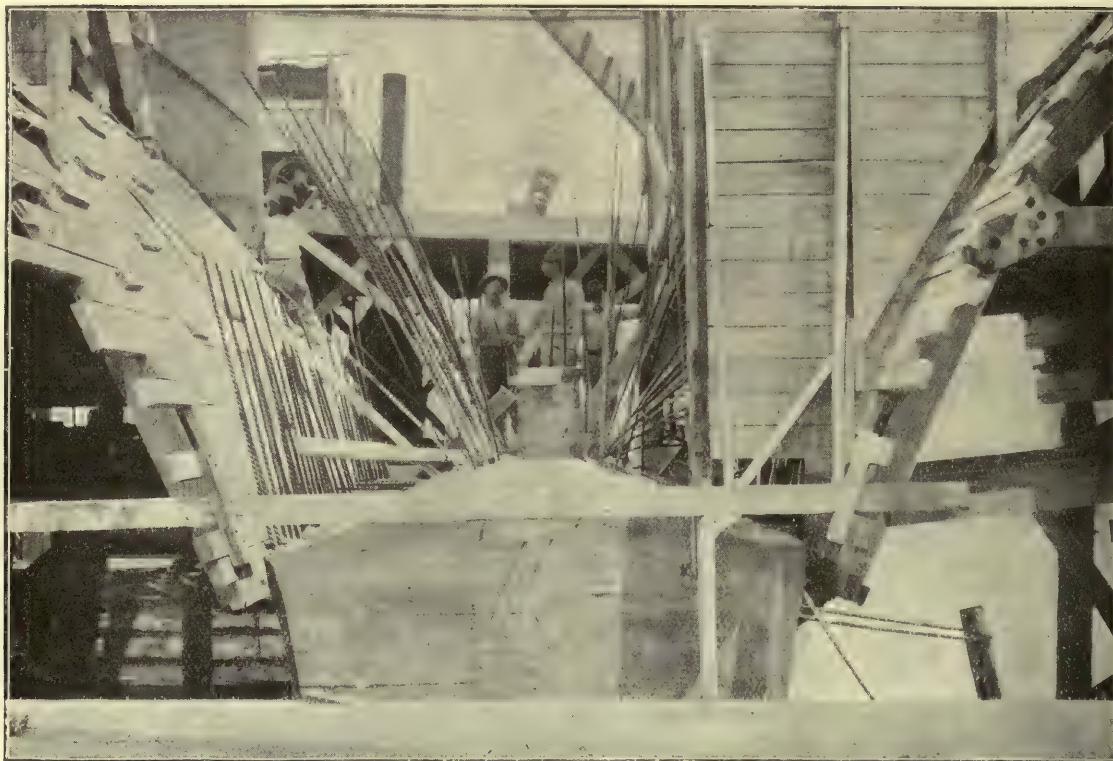
BUILDING UP AN ARCH PIER OF REINFORCED CONCRETE.

Notice the twisted steel reinforcement Rods.

smother of sea and a roaring wind, and was smashed on the back of the Florida Reef. The great barge was pounded to pieces in a few minutes. But there were men in her who showed heroic stuff even in this terrible situation. Bert A. Parlin, one of the resident engineers, and the ranking man aboard, might have saved himself; but he went below to try to put heart into his men, and was killed by a flying beam when the superstructure collapsed. (These boats boasted of a two-story superstructure on their decks, and were towed from key to key as the work advanced.) The men who had the grit and courage to use their wits crowded out on the balcony to windward to escape this falling wreckage, and swore that they would pull through. Those who had the will to live were saved under almost incredible circumstances, while the cowards who had crowded into the hold perished to a man. As the quarter-boat floundered toward the reef, with the seas breaking clean over her, with death for all on board apparently certain, a barge whirled past her in a fog of spray. Two mechanics, Kelly and Kennedy, stood side by side on the deck of the houseboat.

"'That barge looks good to me,' said Kelly.

"'I'll go with you,' replied Kennedy.



ARCH AND SPANDREL WALL MOULDING FRAMES IN PLACE.

"Kelly jumped for the barge as it sped past, and Kennedy was at his heels. A gray sea rose and swallowed them, and their comrades counted them as lost. Almost a week later, the barge was picked up with Kelly and Kennedy aboard, crazed and almost dead for want of food and water. They recovered, and returned to the keys. As many as eighty-seven of these quarter-boat men were picked up out of the sea alive. With remarkable strength, and with courage truly indomitable, they had ridden out the hurricane clinging to bits of wreckage, to tables, and to trunks. The Italian steamer *Jenny* passed them late in the afternoon of the day of the wreck, found forty-four of them, and took them into Key West. Her boats risked the dangerous seas all night long, and it is tragic to record that they heard the voices of others in the darkness, but were unable to locate the calls for help The British steamer *Alton* picked up twenty-six more, and landed them at Savannah. For days and weeks news of other castaways came from distant ports—Mobile, Galveston, New York, London, Liverpool, and even from Buenos Aires, whither they had been taken by ships.

Stories of Disasters.

"Of forty-nine men who went to sea in two houseboats, only one, John Russell, was saved. He floated on a couple of planks for three days, was blinded by salt water, and heard ships pass him in the night before he was seen and picked up and taken into New York. There was something fine about the finish of one—Mullin—left in charge of a cement-mixing plant on board a barge. He was alone when she was blown out to sea, but there was an electric light plant on board his craft, and as long as those on shore could see her in the gray dawn, Mullin's lights were blazing like a Coney Island steamboat. He was

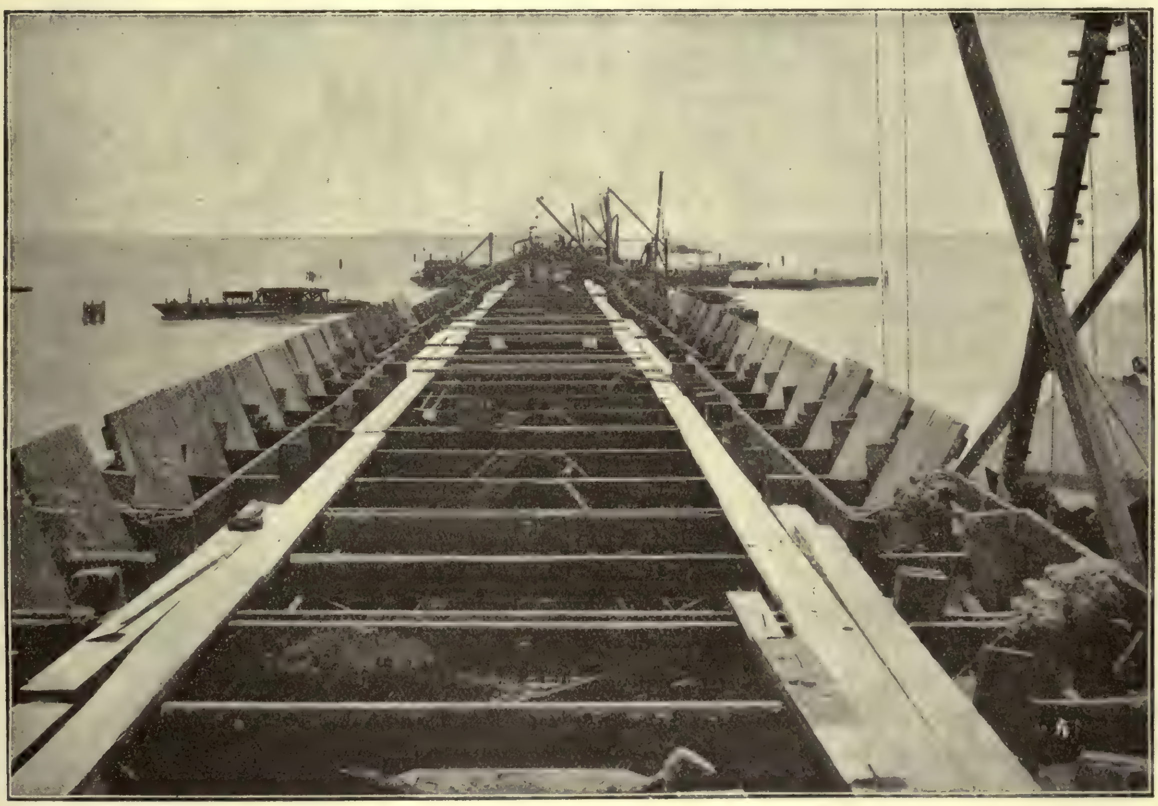
stoking his boiler and sticking to his job until the moment when the sea swallowed him up. Another lone hero on one of these cement barges found himself blown out into the wild Atlantic. Instead of giving up the game as hopeless, he set to work with his wrench to loosen the bolts which held the cypress box of a water-tank to the deck. Stowing himself in the tank, he stayed there until the barge sank under him; the big box floated off, and he drifted in it right side up for several days until he reached the coast of Nassau."

Knight's Key Terminus.

As soon as the line was finished to Knight's Key, a distance of 109 miles from Miami, it was decided to erect a station here, build a dock, and make it a place of call. A trestle embankment 2,000 feet long was consequently carried to the dock, which is connected with the open sea by a deep channel, permitting vessels of twenty feet draught to come alongside the dock itself. Between Knight's Key and Pigeon Key there is an opening of 10,250 feet. Of this distance, 7,300 feet is crossed by a viaduct. We now come to another gap, some 22,900 feet in length, which is bridged by a 7,800-foot viaduct and by some very long embankments. Between Bahia Honda Key and West Cumberland Key another gap occurs of 5,600 feet, 4,950 feet of which is spanned by a viaduct with a 250-foot drawbridge for vessels.

Dredging in the Islands.

Many of the islands, particularly those below Bahia Honda, are mere swamps, densely covered with mangrove. To throw up an embankment across them was largely a matter of dredging, and for this particular kind of dredging the engineers constructed a new type of machine. To feed any



CONSTRUCTING LONG KEY VIADUCT.

VIADUCT ALMOST COMPLETED.

of the usual type of dredge with coal and fresh water was impossible, because supplies could not be transported over the shoal lagoons and landed within reach. The dredges used here were operated by gasolene engines. Six of them were constructed on barges. Where there was enough water to float them they waddled across the key, indefatigably heaping up embankments. When they came to a dry bit of going they were hauled ashore, mounted on wheels, slid on to a steel track, and so moved ahead as effectively as ever. Upon these embankments miles of trestlework were built, and white coral and sand dumped in. This in time hardens to solid limestone rock. Then came the graders, followed by the track-layers. In this way key after key was bridged for the iron road.

One of the greatest difficulties of the whole undertaking was that of obtaining fresh water, which had to be transported in tanks from Miami, a distance of more than 100 miles. At one time it was thought to cut this distance down by hauling water from Manatee Creek, 50 miles away. Accordingly a water station was put in, and an attempt made to haul water from that point. A north-west wind came along one day and blew the water out of the bay, so that it was impossible for boats to get within two miles of the water station, and they had to go back to Miami until the water regained its natural level. Three weeks later the wind came from the south-west, and piled the water up in the bay far above normal level.

On the viaducts and embankments in the open sea the track is kept at a level of more than 30 feet above high water. It has been found, after careful examination, that the maximum height of waves throughout these waters is 25 feet. The highest waves known in these regions, therefore, could not break over the top of the viaducts or embankments. It is in the fall of the year, during the months of September and October, that rough weather is experienced in the Bay of Florida. It should be stated, perhaps, that, although the viaducts are of tremendous length, they do not by any means complete the connections. For instance, the viaduct across Long Key channel is 10,500 feet in length, but the embankments at each end bring its total length up to 19,100 feet. Many of these ramparts were thrown up by suction dredges, which trailed their long lines of pipe across the channel like huge serpents. These crossings were then riprapped (faced) with rock in order to protect them against the wash of the sea. Here and there, too, special bridges had to be erected. These had to comply with the requirements of the officials at Washington.

Track 30 feet above Water.

CLOSE VIEW OF A COMPLETED VIADUCT.

One boasts of 100-foot clearances each side of a central pier, while there are two bridges with 40-foot clearances, and seven bridges with fixed openings of 25 feet. The arches have openings of from 50 to 60 feet.

No contractors were employed, the work being carried out entirely by the Florida East Coast Railway, which appointed Mr. J. R. Parrott as the director of the works, and Mr. J. C. Meredith as construction engineer. The latter is a famous bridge-builder, and is regarded by his brother engineers as a man of much courage and resourcefulness. He certainly showed these qualities while engaged in the construction of this unique railway. It is said that when Mr. Parrott summoned him to confer with him, he expected that the engineer would demand a month to look over the ground and another month to make up his mind. To Mr. Parrott's surprise, when the proposition was put to him, and he was asked whether he was prepared to undertake it, he replied, "I am ready to begin work this afternoon, but I'd like a few days to go home to Kansas City and pack some things and see my family, as I'll have to be on this job for several years."

The Engineers.

In May 1905 construction work was begun. By the following January ten camps, scattered throughout the entire distance of the Floridan Archipelago, had been established. By midsummer these camps had doubled themselves, and before 1906 was ten months old thirty were in full swing. On January 22, 1907, the first passenger train ran to Knight's Key, 109 miles south of Miami, and only 47 miles from the ultimate end of the line at Key West. It was a private train, and consisted of two coaches. In the first sat Mr. Henry M. Flagler (whose seventy-eight years only made him the more boyishly keen to see the attainment of his great ambition), his wife and daughter, and their friends. The second coach contained prominent officials of the line. In crossing over the great viaduct at Long Key land is entirely lost to view, nothing appearing

Progress of the Work.

LONG KEY VIADUCT.

on one side but the wide expanse of the Atlantic, and on the other the waters of the Bay of Florida. Those who journeyed on this train were charmed with the ride. For long stretches the track is shaded by waving forests of cocoanut palms, which, set off by the dazzling white of the coral, make an enchanting scene. On the following day regular passenger trains were run to Knight's Key, and the Occidental Steamship Company put on a direct boat service from this terminus to Havana, 115 miles away. By this move a half day was clipped at one stroke from the travelling time between New York or Chicago and Havana.

VIEW FROM THE TRACK.

Portions of the Railway run through forests of cocoanut palms.

At the time of writing more than 90 per cent. of the construction work of the remaining stretch had been accomplished, and the summer of 1909 should witness the fulfilment of Mr. Flagler's dream—an all-rail route from New York to Havana. On account of many of the keys below Knight's Key being virtually swamps, and the road across them having to be built up laboriously from the level of the sea, work was naturally slow. Also, some of the channels which have been bridged were of considerable size, and subject to the full force of the Atlantic, so that for them very massive embankments were needed. Every now and again the builders surprised lonely dwellers who have lived for years on the islands in Robinson Crusoe fashion. One, a picturesque Spaniard, declared that he had dwelt alone on a small key for thirty years, subsisting on fish, birds, and fruit. Tiny clearings were brought to light which the *aguardiente* smugglers from Cuba have made their rendezvous for generations. Every Cuban revolution for a century past has sent vessels to flit among these keys and pick up hidden stores of arms and swarthy leaders waiting to return from exile.

Lonely Dwellers on the Keys.

While the railway builders were busy laying their iron road across the channels and over the keys, an army of labourers, directed by competent engineers, were set to work to transform Key West into an up-to-date commercial port. This work is still going on. The present plan includes the erection of one large dry dock and ten wharves, each 800 feet long and 100 feet wide, with basins 200 feet wide lying between. The great piers will afford berths for forty boats four hundred feet long. The depth of water is from twenty to forty feet. This work will be completed during the present summer, when for its harbour facilities as a commercial port Key West will almost immediately rank with New York, New Orleans, and Galveston.

Transforming Key West.

Although a single-track railway, the extension has cost over £3,000,000 to build, or over £20,000 per mile. It is expected, however, to be in every sense of the word a financial success. It brings New York within close touch of Cuba, and also much nearer the Panama Canal, the West Indies, and the

£20,000 per Mile.

States of South America. The journey naturally appeals to the tourist, as it is the only railway which runs for many miles over the sea. The traveller can locate his bearings when he leaves the mainland only by the numerous lighthouses which rise from the sea on their skeleton legs, and are visible from the carriage windows. Sombrero Reef, Alligator Reef, and American Shoal lighthouses take the place of milestones, which is just as it should be on a sea-going railway. Throughout the journey the ocean ships are seen from the carriage windows—the vessels that ply regularly between the ports on the Atlantic coast of America, Cuba, the West Indies, and the Central and Southern States of South America.

GENERAL VIEW OF LONG KEY VIADUCT.

IRISH MAIL LEAVING THE BRITANNIA BRIDGE. *(Photo, London and North-Western Railway Company.)*

An Account of the Wonderful Suspension and Tubular Bridges built by Thomas Telford and Robert Stephenson more than half a century ago, and still in everyday use.

Travelling from England to Ireland.

At the commencement of the eighteenth century a voyage from England to Ireland was not lightly undertaken. The vile condition of the Welsh roads compelled travellers to make either Bristol or Liverpool the port from which to sail. The ships of those days were far from being commodious or comfortable, and when, as often happened, contrary winds and storms protracted the voyage, the passengers fared badly. Now, the map shows very clearly that Holyhead, at the north-west corner of the island of Anglesey, is much nearer the Irish coast than is either Liverpool or Bristol, and this geographical fact presently made it the fashion to brave the joltings of Welsh mountain tracks in preference to the tossings of seventy miles of Irish Sea. It is true that the Holyhead route included the crossing of the Menai Straits, which, in certain states of tide and weather, was a very unpleasant business; and when these had been negotiated, there remained the roads of Anglesey, which were, if possible, worse than those of Wales. To the credit side of the Holyhead route could be placed the fact that Anglesey and Liverpool were equidistant from many of the large midland and southern towns.

Telford's Road to Holyhead.

In 1810 the great engineer, Mr. Thomas Telford, was engaged to deal with the roads between Shrewsbury and Holyhead, *via* Llangollen, Bettws-y-Coed, and Bangor. He blasted rocks, built parapets, and formed embankments, until, in the place of rough, steep mountain tracks and tenacious quagmires, there was a wide, safe, and splendidly graded road, which even at this day is one of the best in the British Isles.

He decides to bridge the Menai Straits.

But there still existed the irksome passage of the straits. Until these were bridged the road would be incomplete. Mr. Telford undertook to span the gap. He submitted two plans for arched bridges, one of which showed a 500-foot cast-iron arch, to be supported during construction on centres suspended from large frames rising on the two shores. Both these plans were ruled out, however, on the ground that they would interfere seriously with the navigation of the straits; so the engineer decided on a suspension bridge which should clear the water by 100 feet or more—sufficient to permit the passage of a tall ship. The site chosen was at a point where the shore on either side rises steeply, and where the straits are about 800

feet wide at high tide. The distance between abutments is just short of one-third of a mile. To span this, Telford specified two short embankments, 7 arches of 52½ feet span, and a main suspension span over the channel of 550 feet between the centres of the towers.

The last factor taxed Mr. Telford's ingenuity severely. Such a span was at the time unprecedented, and the safe accomplishment of the task demanded that a vast amount of preliminary experiment should be devoted to the huge chains forming the distinguishing feature of the structure.

THOMAS TELFORD,
Designer and Engineer of the Menai Suspension Bridge.
(From the Rischgitz Collection.)

An Act empowering the building of the bridge was passed in 1819, and Telford lost no time in getting to work. The foundations of the two main piers, each 153 feet high, were taken in hand first, and while the piers rose the arches of the two approaches rose with them, the chief difficulty being that of providing sufficient stone to keep the army of masons engaged.

The Building of the Piers.

As the piers would be subjected to severe lateral strains, their individual stones were bound together by iron clamps, in much the same manner as the components of a lighthouse. Four large cast-iron saddles, running on rollers, to carry the suspension chains, capped each pier. Their easy movements over the rollers provided for the expansion or contraction of the chains as the temperature of the air should vary.

Anchoring the Suspension Chains.

Since the efficiency of a chain depends ultimately on secure attachment, every care was taken to ensure firm anchorages for the chains of this bridge. The method adopted was to drive four parallel tunnels obliquely down into the native rock for a distance of 20 yards or more, and excavate a chamber across their lower ends. In this chamber were built up massive transverse anchorage frames, resting against the walls of rock separating the tunnels, and therefore immovable unless the rock itself were torn away — a contingency that was practically negligible.

The chains, sixteen in number, were composed of ½-inch bars of iron. Thirty-six bars—corresponding to the strands of a wire cable—were grouped together to make a square chain four inches on the side, the components of the chain being wrapped with iron wire. The weight of the portion of the chain between the two suspension piers was over 23 tons ; its length, 570 feet.

The masonry completed, preparations were made for hoisting the chains into position—a process to which Mr. Telford looked forward with the greatest anxiety. In order to obtain exact figures as to the power required to hoist

a chain and give it the correct curvature between the piers, he fastened together, end to end, a number of iron bars totalling five hundred and seventy feet in length. These were laid out in an adjacent valley, and raised at the ends until the centre was clear of the ground and the curve was the same as that

An Experiment.

MENAI SUSPENSION BRIDGE FROM THE CARNARVON SIDE. *(Photo, Valentine and Sons.)*

of the suspension chains to be. From the stresses recorded, Telford calculated that a pull of thirty-nine and a half tons would be needed to handle the central span of a chain.

Each chain was divided into three parts—two to reach from the anchorages to the piers, the third to span the channel. One of the land sections—that on the Carnarvon side—was long enough to extend down the seaward side of this pier to water-level; the other reached only to the pier saddle. The rest of the chain was built on a raft 450 feet long and 6 feet wide, ready to be floated to a position between the two piers.

On April 14, 1825, the hoisting of the first of the chains took place under the eyes of thousands of people who gathered from far and near to witness the subjection of the straits. In the afternoon, shortly before high water, the raft bearing the chain was taken in tow by four boats, swung round, and moored across the straits on the line of the bridge. One end was then made fast to a loose end of the Carnarvon section, and to the other were attached strong ropes leading over the top of the Anglesey pier to two capstans on the shore. At the given signal 150 sturdy labourers threw their weight on the capstan bars. Slowly the chain rose from the raft, and yet more slowly, as less and less weight was water-borne. Presently a great shout arose when the raft, now entirely freed from its load, floated down the tide. For another hour the crowd watched the curve of the chain grow flatter and flatter, and the word went round that a junction had been made with the Anglesey land section—in fact, that a continuous chain now extended from Anglesey to Wales. This provoked a fresh outburst of cheering, which in turn encouraged some foolhardy workmen to use the chain as an unlicensed bridge and win the perilous honour of being the first to cross the straits by an aerial pathway. Not that

Hoisting the Chains.

The Junction made.

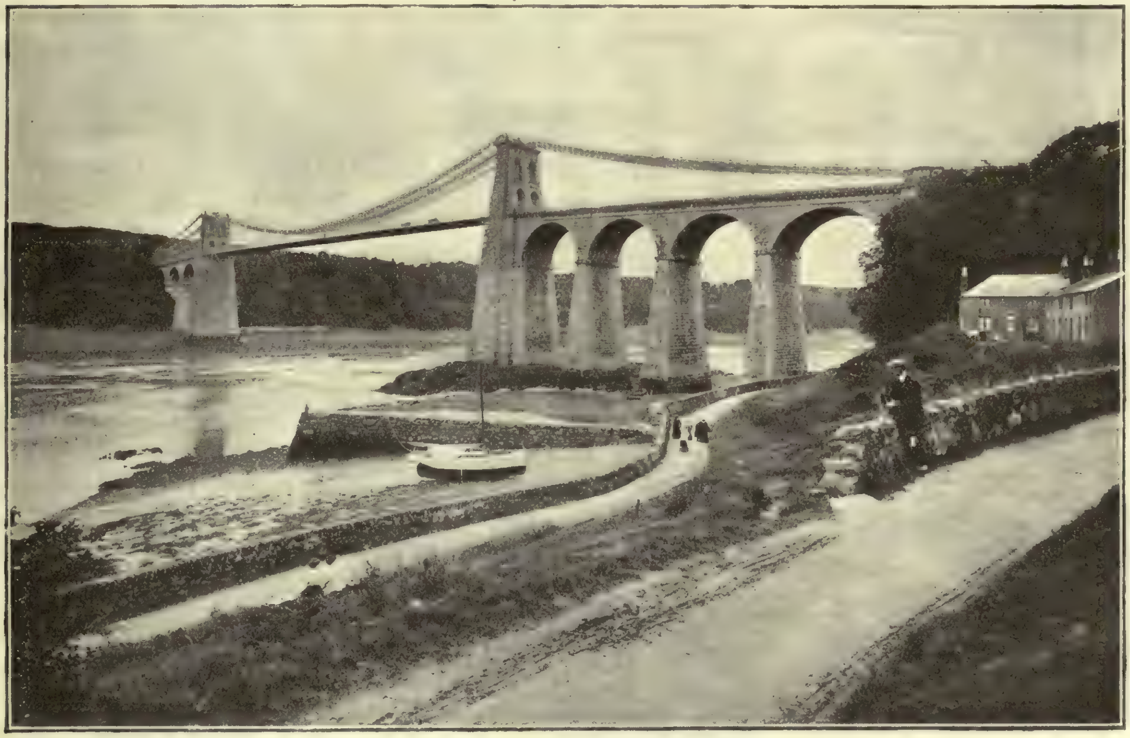
they were so daring as a workman on the great cantilever bridge across the Niagara gorge, who, when but a narrow gap separated the two cantilever arms, laid a plank across it, walked deliberately to the middle, and stood on his head, kicking his legs about just to show how little he cared for the whirlpool raging two hundred feet below!

A Foolhardy Feat.

bars of inch-square iron. By the end of the year the structure was complete, and on January 30, 1826, a stage-coach made the passage of the bridge at the head of a great procession of people of all ranks.

This remarkable bridge has a roadway length of just 1,000 feet, while the suspension chains measure 1,715 feet from anchorage to anchorage. The roadway, 30 feet wide, gives accommodation for two carriage-ways and a footpath. Over 33,000 pieces of iron, weighing 2,187 tons, are incorporated in the structure, the cost of which was £120,000. During a gale the bridge oscillates slightly, but the crossing of heavy vehicles does not affect it sensibly.

Facts and Figures.



MENAI SUSPENSION BRIDGE FROM THE ANGLESEY SIDE.

(Photo, London and North-Western Railway Company.)

The remaining fifteen chains were raised in the same manner as the first, and by July 9, 1825, the last was in place. A band ascended to a temporary platform on the centre of the span and played the National Anthem to the crowds which had assembled for the occasion. Then followed the more prosaic work of attaching the roadway of stout planks to the vertical suspension

The Bridge opened.

Simultaneously with this bridge Telford erected one of similar construction across the

GENERAL VIEW OF THE BRITANNIA BRIDGE WORKS, SEPTEMBER 1848.

The Towers almost completed.

(From an Old Print.)

mouth of the Conway River, to benefit travellers on the Chester-Holyhead road, by abolishing the need for ferrying across the river. The Conway Bridge, which has a central span of 327 feet and a width of 32 feet, was also opened for traffic in 1826.

The Conway Suspension Bridge.

Though now more than eighty years old, both these bridges are, to all appearance, "as good as new," and there is no reason to doubt that for many years to come they will stand as a memorial to the engineer who greatly dared and successfully accomplished.

THE BRITANNIA BRIDGE.

In countries of old civilization first comes the road, then the railway. The twelve years that followed the completion of Telford's suspension bridges were remarkable for the development of the steam railway. By 1838 George Stephenson was surveying with chain and level the line of the Chester-Bangor road along the north coast of Wales, with a view to constructing a railway to Holyhead. For the crossing of the Conway estuary of the Menai Straits the bridges then existing could, so Stephenson maintained, be used for trains, though he considered that it would be advisable to relieve the Menai Bridge by moving trains over it by living horse power, as the concentrated weight of a locomotive might be expected to cause serious undulations of the roadway.

The Chester-Holyhead Railway.

ROBERT STEPHENSON,
Designer and Engineer of the Britannia Tubular Bridge.
(*From the Rischgitz Collection.*)

When Robert Stephenson took over the construction of the railway from his father, it was decided that special bridges for trains should be thrown across the Conway and the Menai Straits, and he was asked to draw out designs. The site selected by him was about a mile south of the suspension bridge, where the waterway is some 900 feet across at high tide, and where a rock, named the Britannia Rock, rising in mid-channel, offered a convenient base for a central pier. Like Telford, Stephenson first designed an arch bridge, his having two main spans of 450 feet each; and, like Telford, he incurred the displeasure of the Admiralty, who demanded a bridge which should give a clear headway of 100 feet right across the channel, not at certain points only. Furthermore, My Lords forbade the obstruction of the waterway while the bridge, of whatever type it should be, was in course of construction. The arch principle having been ruled out, and the suspension principle being unsuitable, Stephenson's choice was narrowed down to a stiff truss of some kind.

A Bridge required for the Menai Straits.

An Arch Bridge projected but disallowed.

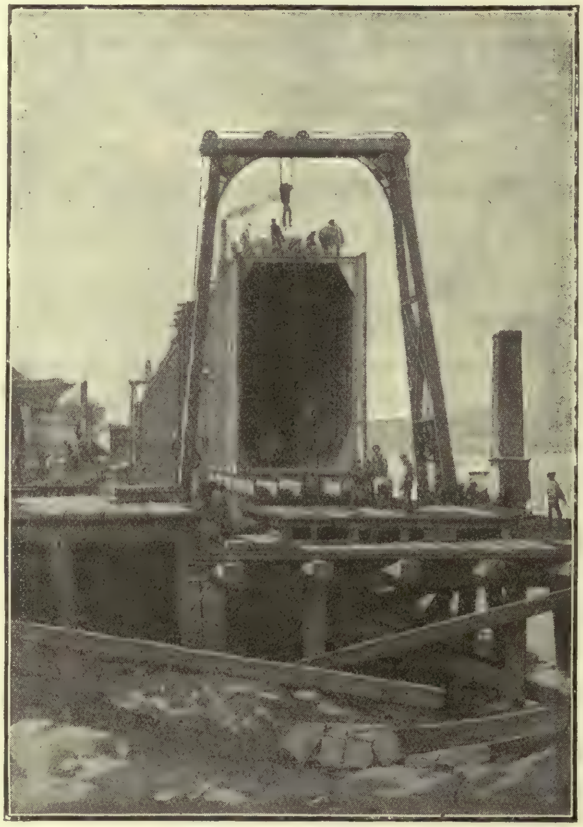
It occurred to him that huge iron tubes, large enough for trains to run through them, might be made of sufficient stiffness to span a gap of 450 feet or more. The most efficient form, and the disposition of metal in the tube, were made the subject of exhaustive experiments,

Plans for a Tubular Bridge.

in which Mr. William Fairbairn took an important part. Model tubes of one-sixth full size were constructed and tested, and from the results so obtained was established the superiority of rectangular tubes, specially strengthened at the top, over tubes of circular or elliptical section.

The following was the general scheme of the bridge, for the erection of which parliamentary powers were sought. On the Britannia Rock, and on the shores of the straits, at about high-water mark, would be built three huge piers of masonry, having openings 100 feet above high-tide level (for the tubes). The four tubes of the two main spans were to be 460 feet long, 15 feet wide, and 30 feet high at the Britannia Tower, whence they tapered slightly vertically towards the shore. For the two land spans, four tubes, 230 feet long each, would be needed. All eight tubes were to be built up of riveted boiler plates, ranging from $\frac{1}{2}$ inch to $\frac{7}{8}$ inch in thickness, supported internally by strong ribs of angle iron, and strengthened at the corners, to prevent distortion, by triangular gussets. The roof of a tube was composed of eight flues, 21 inches deep and 20 inches wide, as experiment had shown that a group of flues gave, for a fixed weight of metal, greater strength to the top member than could be obtained from plates assembled in the same way as those of the sides.

Chief Features.



ASSEMBLING A 460-FOOT TUBE ON TEMPORARY PLATFORM.

(*From an Old Print.*)

Huge Tubes.

Stephenson decided to build the short land tubes in their final positions on "falsework" of stout timbers, and, as the Admiralty conditions prohibited this system for the main spans, to take a leaf out of Telford's book and construct the tubes for the latter on platforms on the Carnarvon shore, float them between the piers, and raise them to their final elevation by means of hydraulic presses.

As soon as Stephenson's plans had received official sanction, preparations were begun for pushing the work ahead vigorously. Fifteen hundred workmen were collected, and soon the shores of the straits echoed with the blows of mallets and hammers. When the wharves, workshops, and other temporary structures had been built, large gangs of masons attacked the Britannia Rock and the sites of the two land towers and abutments, while labourers, aided by many horses and carts, heaped up the approach embankments of the bridge. Ship after ship came to anchor in the straits

A Busy Scene.

with its load of timber for the scaffoldings or of stone for the masonry.

The building of the towers and abutments was in itself a great work. The 230-foot Britannia Tower alone consumed 150,000 cubic feet of Anglesey marble and as many feet of limestone; and even greater quantities were needed for the two land towers, each 160 feet high. To render the elevation of the large tubes possible, vertical openings were left in the masonry of all three towers, in which the ends of the tubes would move upwards to their berths like the frame of a window in its sash.

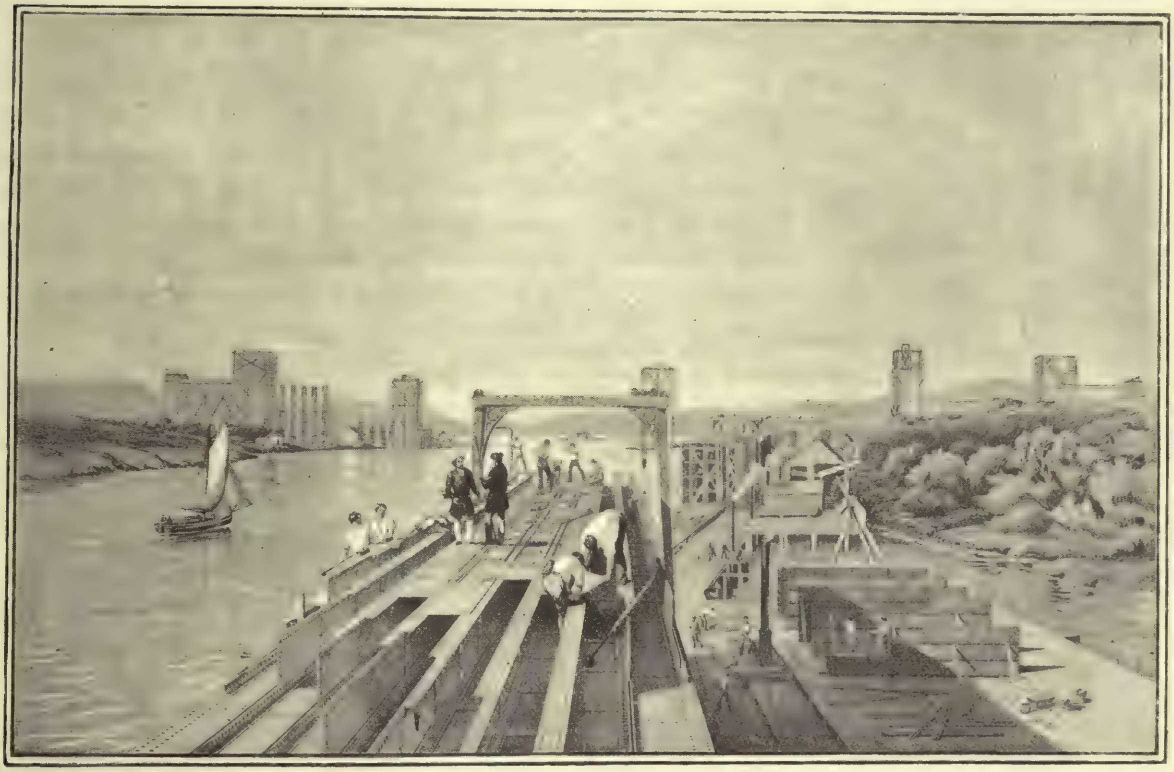
Material needed for the Towers.

While the towers and land spans were in progress, gangs of riveters working on the shore platforms joined up the plates and other members of the main spans. No fewer than two million rivets, each four inches long and seven-eighths of an inch in diameter, and totalling nine hundred tons in weight, were used to hold the tube plates together.

Riveters and Rivets.

When the first of the tubes approached completion, a portion of tne wooden platform under each of its ends was removed, and the rock beneath excavated to form a dock large enough to accommodate four pontoons, each 98 feet long, 25 feet wide, and 11 feet deep. All eight pontoons were furnished with large valves, through which the water passed in and out as the tides rose or ebbed. The combined buoyancy of the pontoons—3,200 tons—exceeded the weight of

Preparations for floating the First Tube.



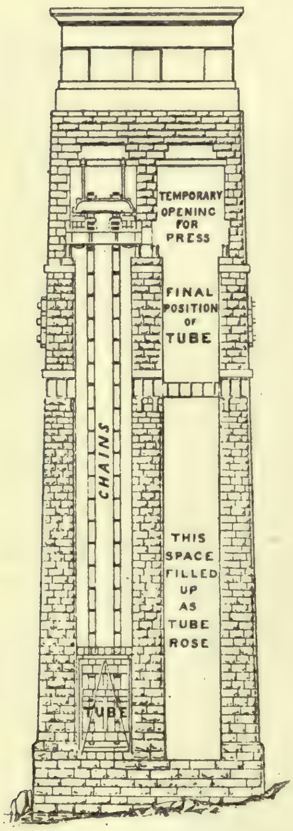
CONSTRUCTING THE CELLULAR ROOF OF A TUBE.

Observe the rivet boys throwing up heated rivets to the "catcher" on the tube.

(From an Old Print, by Permission of the London and North-Western Railway Company.)

the tube and its apparatus by about 1,400 tons.

By the middle of June 1849 tube No. 1 was ready for moving. In the upper part of each of the towers for which it was destined had been placed iron beams, 40 feet above the rectangular tube openings, to support a hydraulic press of 2,620 tons lifting power. Each of the two cylinders of a press was 9½ feet long, nearly 5 feet in diameter, and weighed 16 tons. Its piston had a diameter of 20 inches and a stroke of 6 feet, and moved in a vertical direction. To its upper end was attached a cross-beam, from which depended two chains, composed of series of eight or nine flat plates bolted firmly together. The links were 6 feet long, and "stepped" near the eyes, so that when the press had made its full stroke the chain could be gripped by a huge clamp, and sustained while the piston was withdrawn for the next lift and given a fresh grip in the chain. Each chain was 145 feet long and weighed 25 tons.



Elevation of the Britannia Tower, showing position of Hydraulic Press, Chains, and Tube.

The Hydraulic Presses.

The floating of a tube to the bottom of the towers was no easy matter, owing to the strength of the current running through the straits. Elaborate precautions, including the provision of guide-ropes and capstans, were taken for controlling the pontoons and their freight, and swinging them gradually across the channel as they neared the towers.

The Tube afloat.

On the evening of June 19 a huge crowd began to gather from far and near. Spectators knew that they would behold such a sight as most of them were never likely to see again. As the tide came in, the pontoons, of which the valves had been closed, lifted slowly, shouldering their mighty load. Presently the shout arose, "She floats!" But a slight accident prevented operations being continued till the following evening, when the pontoons swung out into the channel, one end of the tube describing part of a circle. Guided by its hawsers, this strange craft moved slowly down towards the bases of the towers, in which recesses had been prepared for the tube. As it got broadside on to the current the pull on one of the controlling capstans became so violent as to drag the mechanism bodily from its foundations. For a few moments it looked as if this first launch were to end in disaster. Fortunately, Mr. Charles Rolfe, who was in command of the capstan, had the presence of mind to shout to the spectators to seize hold and check the progress of the tube. A crowd of men, women, and children flung themselves upon the rope. There ensued a tug-of-war in which human muscles bested the pull of the tide, and the tube was brought up safely with its ends over the recesses cut in the towers. As the tide sank the ironwork came to rest in the exact position required by its designer. So accurately had all calculations been made that, though the tube was 460 feet long, there remained between the ends of the iron plates and the walls of the recesses a space somewhat less than an inch!

A Mishap and a Rescue.

The first act of the play was finished. Little time was lost in proceeding with the second. The chains of the hydraulic presses were made fast to the lifting cradles attached to the tube

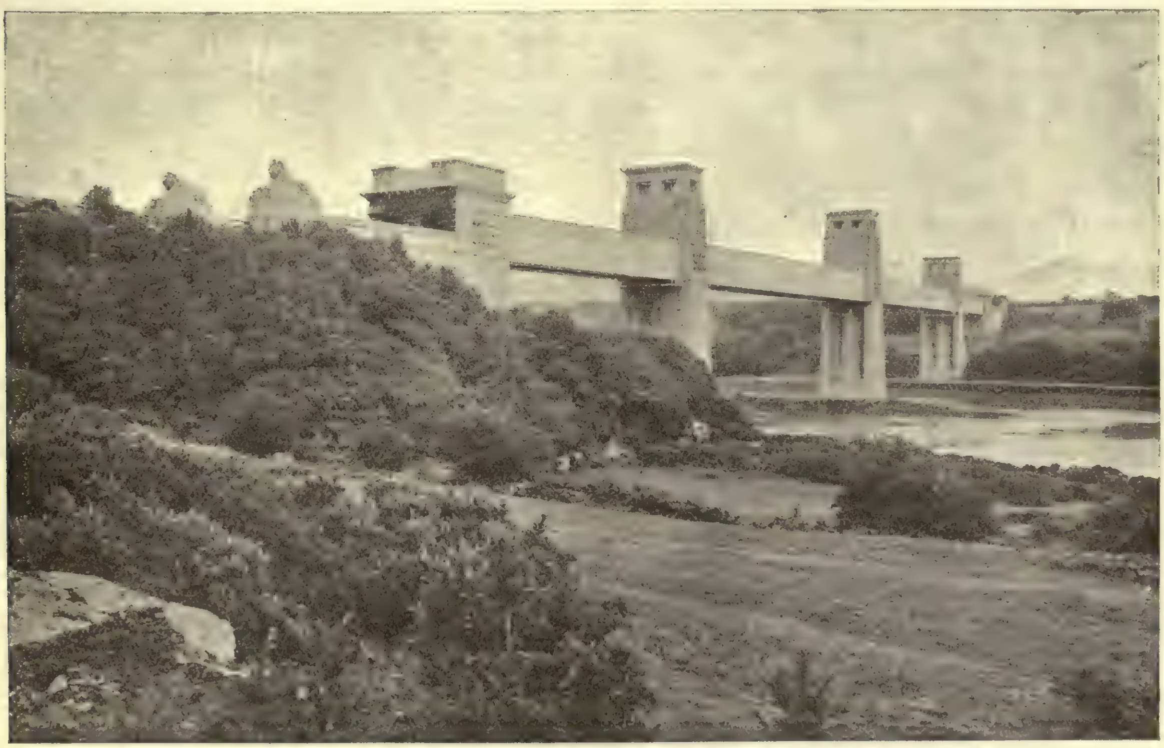
ends. The steam-engines perched on the towers began to force water at enormous pressure into the cylinders of the presses; the rams emerged slowly. As the tube ascended, the masonry was built in underneath it, so that there should never be a clear space of more than a few inches under the iron-work. Robert Stephenson had insisted beforehand that, though the strength of the beams supporting the presses, and of the chains, was sufficient to bear the load, no risks were to be taken.

Raising the Tube.

The ends of the tube were lifted alternately, and they rose gradually to a height of about 30 feet. Then occurred an accident which proved only too conclusively how justifiable was Stephenson's caution. Without the least warning, one of the hydraulic presses burst, and the tube fell 7 inches on to the packings which had been built up underneath it. So small a fall may appear to the uninitiated to be of slight consequence; but the momentum acquired by the 900 tons of iron grew, even in that small distance, to such proportions as to crumple up solid castings, weighing tons, as if they had been mere biscuit boxes. "Thank God," wrote Mr. Clark, the engineer in charge, to Stephenson, "that you have been so obstinate; for if this accident had occurred with no bed for the end of the tube to fall on, it would have now been lying across the bottom of the straits." As it was, this accident strained the tube, though fortunately not to a serious extent, and added an item of £5,000 to the cost —£234,450—of building the bridge.

A Serious Disaster averted.

A new cylinder having been provided, the tube was raised to its final position; and in due course its three gigantic brothers, each of which, if stood on end in St. Paul's Church-



THE BRITANNIA BRIDGE AS IT IS TO-DAY. VIEW FROM ANGLESEY SIDE.

(*Photo, London and North-Western Railway Company.*)

yard, would tower 100 feet above the great cross, were set in their respective places.

All the Tubes raised.

All four tubes for each track of rails were then joined together to form a continuous girder, 1,511 feet long, and weighing 5,000 odd tons, attached firmly to the Britannia Tower, but resting upon rollers on the two land piers and the abutments, to allow for expansion and contraction of the metal.

On March 5, 1850, the now completed bridge was subjected to severe tests. First, three locomotives, coupled together, were moved

Testing the Bridge.

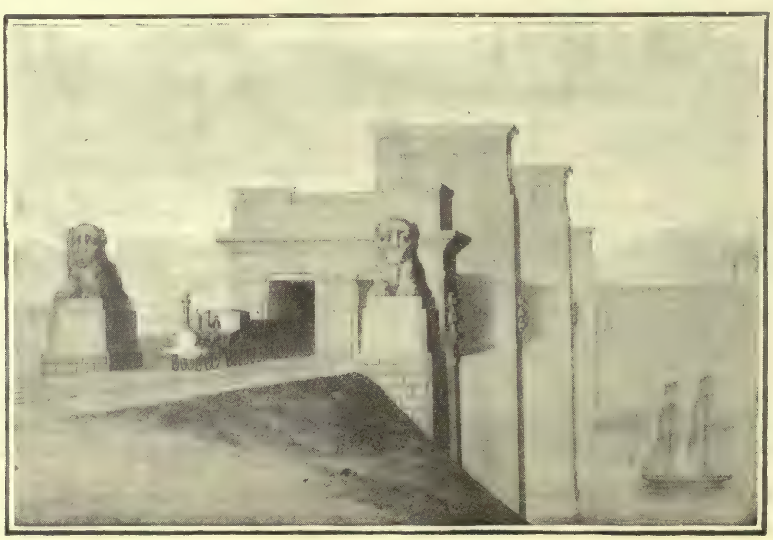
across; then a train of twenty-four loaded coal wagons; and finally a heavy testing train of several hundred tons crossed at a speed of 35 miles an hour. The deflection caused by the load was less than half an inch, or barely one twenty-fifth of that to which the bridge might be subjected without danger. As Stephenson had designed the bridge to stand eight times the maximum load that could possibly be put upon it by an ordinary train, the slightness of the deflection was anticipated. Though the weight of locomotives and other rolling stock has increased greatly during the last half century, and nearly sixty years have passed since the opening of the bridge, there has been no talk of replacing Stephenson's great structure by one of more modern design.

"The Britannia Bridge," wrote Dr. Smiles, "is one of the most remarkable monuments of the enterprise and skill of the present [nineteenth] century. Robert Ste-

An Appreciation of the Bridge.

phenson was the master spirit of the undertaking. To him belongs the merit of first seizing the ideal conception of the structure best adapted to meet the necessities of the case, and of selecting the best men to work out his idea; himself watching, controlling, and testing every result by independent check and counter-check.

"But for the perfection of our tools, and the ability of our mechanics to use them to the greatest advantage; but for the matured powers of the steam-engine; but for the improvements in the iron manufacture, which enabled blooms to be puddled of sizes before deemed impracticable, and plates and bars of immense size to be rolled and forged,—but for these, the Britannia Bridge would have been designed in vain. Thus it was not the product of the genius of the railway engineer alone, but of the collective mechanical genius of the English nation."



END-ON VIEW OF THE BRIDGE.

(From an Old Print, by permission of the London and North - Western Railway Company.)

IN IRLAM LOCKS. (*Photo, R. Banks.*)

THE MANCHESTER SHIP CANAL.

BY W. T. PERKINS.

This Chapter describes how a great Inland City was made, for practical commercial purposes, a Seaport, accessible to Ships of Large Tonnage.

THIS great scheme, which made Manchester a port, is well entitled to rank among the "Engineering Wonders of the World."

The First Practicable Scheme for a Ship Canal to Manchester.

The advantages to be derived by giving direct access to the sea from the city which Mr. Gladstone once described as "the centre of the modern life of the country" appears to have been recognized nearly two hundred years ago. But it was not until Mr. Daniel Adamson took the matter in hand in June 1882 that any really adequate scheme was brought to public notice. A private meeting at Mr. Adamson's house in Didsbury led to the formation of a Provisional Committee, who invited two engineers—Mr. H. H. Fulton and Mr. Edward Leader Williams—to submit definite proposals. The scheme adopted was that of Mr. Leader Williams, who was afterwards knighted because of his magnificent work. The proposal submitted to Parliament in 1883, and again submitted (with modifications) in 1884, was (*a*) a dredged channel between training walls in the estuary, from Garston to Runcorn; (*b*) a tidal cut through the land from Runcorn to Latchford; (*c*) a locked canal from Latchford to Manchester, so that in the latter city the water might always be maintained at a convenient level, instead of, as Mr. Fulton intended, at a depth of 90 feet below the surface of the land surrounding the tidal basin.

PERSPECTIVE VIEW OF THE CANAL, SHOWING THE POSITION OF THE EMBANKMENTS, WORKS, RAILWAYS (BLACK LINES), AND CANALS (WHITE LINES) IN CONNECTION.

Mr. James Abernethy, a shrewd Scot, whose services as a consulting engineer had been retained, did not hesitate to report in favour of the scheme outlined by Sir E. Leader Williams, and the latter was unanimously approved by the committee. An enthusiastic town's meeting endorsed their action, and within a short time £63,000 was subscribed to defray the cost of an application for Parliamentary powers.

Great Opposition met with.

When launched, in the presence of the writer, before a Select Committee of the House of Commons, in the session of 1883, the project aroused extraordinary interest, and the promoters were at once made aware of the fierce antagonism which they might expect on the part not merely of the port of Liverpool, but of every railway company in Lancashire, as also of a host of other bodies, who thought that their interests would suffer permanently if Manchester ever secured its much-coveted water outlet.

First Defeat.

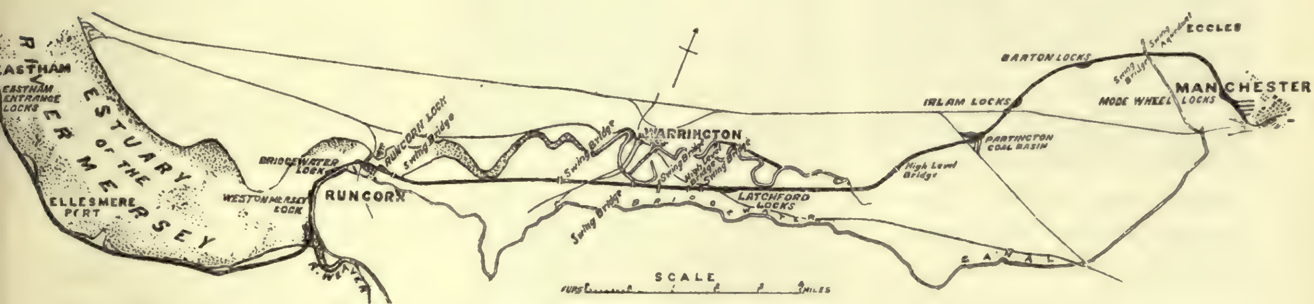
Power was sought to make a semi-tidal waterway between Runcorn and Manchester, and to dredge a channel through the shallower portion of the Mersey estuary. Witnesses came forward to declare that this latter work was calculated to cause a silting up which would ultimately render impossible uninterrupted navigation to the port of Liverpool. But the Committee reported in favour of the measure. In the House of Lords, on the same evidence, the decision was reversed.

Steps were forthwith taken for a further application to Parliament in the following session. This time success attended the appearance of the promoters before a Select

Committee of the House of Lords; but a Commons Committee, while manifesting sympathy with the aims of Mr. Adamson and his resolute supporters, came to the conclusion that the object sought might be attained without incurring the risk apparently associated with the suggested deep-water channel through the estuary.

Second Defeat.

a distance of about 10 miles beyond Runcorn, placing the entrance in the deep water at Eastham, so that the danger of silting up, considered to be threatened by the earlier design, could no longer be suggested. Only the first section of the Canal—namely, that between Eastham and Runcorn—was to be subject to tidal influence, the remaining sections being contained in independent sets of power-



MAP OF THE MANCHESTER SHIP CANAL.

In less than a week after their second defeat, the members of the Provisional Committee had determined to invoke the aid of the Manchester City Council and the Salford Town Council in the promotion of a third Bill. Both bodies responded readily to the call, and each levied a twopenny rate, so that they might have the means of offering a special contribution towards the expense involved. The result was that in 1885 the pioneers were seen to be more in earnest than ever, and they were conscious of the fact that their amended plans avoided the perils which had previously involved disaster.

Third Bill.

Adopting in part an alternative scheme hinted at by some of the ablest engineers who had condemned the idea of making a deep-water channel in the estuary itself, Sir E. Leader Williams and his companions now announced their intention of cutting a semi-tidal canal through the land on the Cheshire side of the Mersey for

An Alternative Scheme submitted.

ful locks erected at Latchford, Irlam, Barton, and Mode Wheel.

It was agreed that the dimensions of the Canal should be as follows :—

Total length	35½ miles.
Average width at water-level	172 feet.
Minimum width at bottom	120 feet.
Minimum width between Barton and Manchester	170 feet.
Minimum width at water-level	179 feet.
Minimum depth when completed	26 feet.
Minimum depth since increased to	28 feet.

The minimum depth decided upon at the outset was exactly the same as that of the Suez Canal, and diagrams were exhibited to the Parliamentary Committee indicating how the new waterway would compare with the famous work of M. de Lesseps, as also with the Amsterdam and other ship canals of minor importance. It was shown that there would be docks in Salford, as well as in Manchester, both above and below Trafford Road Bridge, and a coal basin at Partington. The present dimensions of these docks are :—

The Suez Canal.

Salford Docks.	
Water space	83½ acres.
Quays (area)	252 acres.
Quays (total length)	4 miles.
Manchester Docks.	
Water space	36½ acres.
Quays (area)	34½ acres.
Quays (total length)	2½ miles.
Partington Coal Basin.	
Water space	6½ acres.
Quays (area)	20 acres.
Quays (length)	½ mile.

The promoters also offered to purchase the docks above and below the London and North Western Railway bridge at Runcorn, as these docks formed part of the undertaking worked by the Bridgewater Navigation Company.

A tremendous struggle took place in Committee; and finding that the engineering portion of the scheme was likely to meet with acceptance, the opponents attacked the financial side of the case, declaring that, even if sanctioned by Parliament, the undertaking would speedily become bankrupt, and remain as a standing menace to every interest centred in the Mersey. But the promoters satisfied first one Committee and then another, with the result that in August 1885 the Bill received the Royal assent. The proceedings in Committees alone lasted 175 days, and the cost of obtaining the Act of Parliament (that is, for the three sessions) involved an outlay of nearly £150,000 by the promoters. It was estimated that the opponents incurred an expenditure of £100,000.

Bill receives Royal Assent.

SIR EDWARD LEADER WILLIAMS,
Designer of the Canal.

Those who resisted the enterprise predicted that it would be impossible to raise so large a sum. But the word "failure" was indignantly scouted by all concerned in the realization of the local ambition.

Powers granted in the following session enabled interest to be paid on capital employed during construction. Then came the division of the capital into preference and ordinary shares under the authority of another Act of Parliament. This step secured the co-operation of the great financial houses of Rothschild and Baring, and in August 1887 it was announced that practically the whole of the share capital (£8,000,000) had been allotted, and that the Bridgewater Canal had been purchased for the sum of £1,710,000.

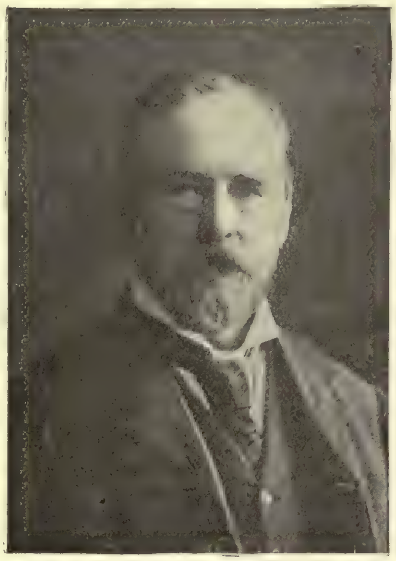
The Bridgewater Canal.

The Bridgewater Canal (about which a few words may be added here), 42 miles long, was designed by Mr. James Brindley, who, although unable to read or write, had peculiar methods of calculating strains and stresses known to himself only. The original purpose of this canal was the conveyance of coal from the Duke of Bridgewater's estate at Worsley to Manchester, at that time an insignificant town with a population of only 20,000. The field of usefulness expanded, and the waterway was extended until it reached Runcorn, the secondary object in view being the conveyance of cotton from Liverpool to the Lancashire mills. The canal gave Manchester cheap coal and cheap cotton, and there followed an extraordinary growth in the cotton industry of the county far exceeding the wildest anticipations of

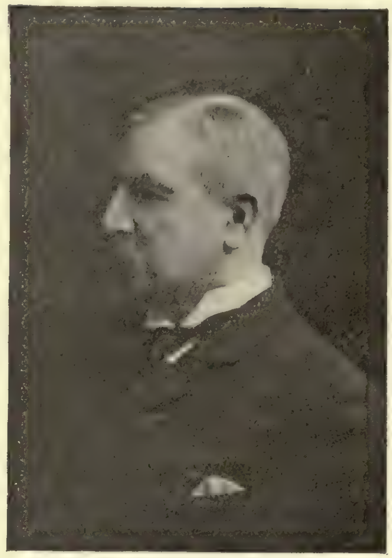
Cheap Coal and Cheap Cotton secured.

those who had brought the canal into existence.

At Barton, Mr. Brindley suggested that the new waterway should be carried over the river Irwell by means of an aqueduct. Parliamentary Committees looked upon this proposal as novel, and some of those who considered the Bill were afraid it would be impossible to prevent the leakage of water from the aqueduct.



MR. J. K. BYTHELL,
Chairman of the M.S.C.Co.
(*Photo, Lafayette.*)



MR. W. HENRY HUNTER,
Chief Engineer.
(*Photo, Lafayette.*)

MR. E. LATIMER,
General Superintendent.
(*Photo, Arthur Reston.*)

MR. HERBERT M. GIBSON,
Chief Traffic Superintendent.
(*Photo, Lafayette.*)

A Practical Demonstration.

But the illiterate engineer requested that a hundredweight of clay should be sent into the Committee Room, so that he might demonstrate the absence of any ground for uneasiness on this score. There and then he modelled a short section intended to represent the canal, and of the water which he poured inside not a drop had disappeared when the Committee reassembled on the following day. The experiment was convincing, and Parliament gave the duke all the powers he requested.

Ship Canal Main Contract.

The main contract for the Ship Canal was entrusted to Mr. T. A. Walker, the contractor who had driven the Severn Tunnel, for £5,750,000, and on November 11, 1887, the first sods were cut at Eastham. To expedite construction, the work was divided into nine sections, each having its own staff of resident and contractor's engineers. Two years afterwards, when all the sections were in hand, Mr. Walker died; and as his executors were unable to complete the contract, the Ship Canal Company resolved to undertake the task themselves. By this time it was manifest, however, that the

original estimates of cost would be entirely inadequate.

By the end of 1890 fully £9,000,000 had been spent, and it was calculated that at least £4,000,000 more would be needed. At this trying moment the Manchester City Corporation came to the assistance of the Canal Company with a loan of £3,000,000, which Parliament readily sanctioned. Five members of the City Council were appointed directors of the company, and with the fresh capital thus available it became possible to complete in September 1891 the tidal section of the Canal from Eastham to the river Weaver. This enabled vessels of large tonnage to reach the Upper Mersey.

Municipal Aid.

But it was obvious that the Canal could not be finished unless another £2,000,000 were raised. Appeal was again made to the City Council for a loan; and although there was no precedent for such heavy obligations being incurred on behalf of ratepayers, Parliament approved further contribution by the municipal authorities. It was stipulated, however, that the board of directors of the Canal Company should be reconstituted, and that the Corporation of Manchester should hold thereon eleven out of twenty-one seats, so that they might always have a preponderating vote.

A Second Corporation Loan.

The directors elected by the shareholders being allowed to appoint the chairman from their own number, in 1894 they unanimously selected, in succession to Earl Egerton of Tatton, Mr. John Kenworthy Bythell, a Manchester man. Mr. Bythell first joined the Board in 1887 with a valuable experience gained in India, where he had for many years been a member of the Bombay Legislative Council. He had also served on the Bombay Port Trust Board, and had taken an active part in the construction by that body of the first wet docks opened in Bombay. In Manchester Mr. Bythell was known as a commercial man of the highest repute, possessing rare administrative ability.

Mr. Bythell appointed Chairman.

EASTHAM LOCKS—PERSPECTIVE VIEW.

Difficulties which no one could have predicted were experienced in every section of the Canal. But the immense labour was pursued with dogged pertinacity.

The entrance is at Eastham, 19 miles above the bar at the mouth of the Mersey. A dredged channel gives access from the deep water of the lower estuary. Three parallel locks form the entrance. They

differ in dimensions, so that they may be used by vessels of varying tonnage. The largest lock is 600 feet long and 80 feet wide; the second, 350 feet by 50 feet; and the third, 150 feet by 30 feet.

Entrance to the Ship Canal.

When the Canal was opened, these locks maintained the water-level at a depth of 26 feet; but the depth over the entire length, as also in the largest dock (No. 9) at Manchester, has since been increased to 28 feet, and the other large docks (Nos. 6, 7, 8) will be deepened to 28 feet before the end of 1909. At each side of the principal lock are culverts 12 feet high and 6 feet wide. These enable it to be filled or lowered with such rapidity that a large ocean-going vessel can pass through in the space of eight minutes, or even less.

Depth of the Canal.

From Eastham to Runcorn the course of the Canal is along the Cheshire bank of the Mersey. Owing to the irregular character of the coast-line, the engineers had to cross three bays, and at each were compelled to erect an embankment dividing the Canal from the estuary.

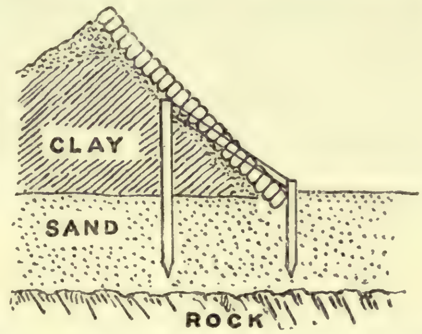
Bays to be crossed.

The first of these embankments, 7,000 feet long, is in Pool Hall Bay. A uniform width was preserved at the top of this embankment, but the height ranged from 10 feet at either end to 40 feet in the centre. Banks of rubble were first formed on the foreshore at either side of the bay; and, as the layer of mud in no place exceeded 24 inches in depth, a firm foundation on the hard clay was soon reached. The space between the banks of rubble was filled with hard boulder clay, and, under the influence of tidal action, this material quickly formed a water-tight mass.

First Embankment.

No difficulty was experienced in making the north and south sections of the same embankment; the foundation of the former for 3,500 feet, and of the latter for 1,000 feet, being stiff boulder clay. But the intermediate portion, 2,500 feet long, caused all sorts of trouble. Mr. Whately Eliot (now Sir Whately Eliot), who was in charge of the Eastham division during construction, has described the first

Many Difficulties.

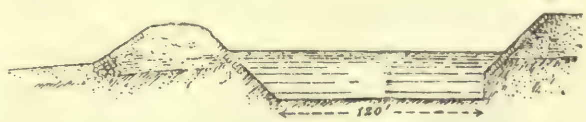


SECTION OF POOL HALL BAY EMBANKMENT.

of these difficulties, which occurred about two thousand feet from the south end of the embankment, where, at the base of the outer slope, a bank of rubble had to be tipped to support the large quantity of clay that formed the hearting.

Here the embankment was 40 feet high, and it had to cross a deep channel scoured by every tide. The rubble bank had been raised to a height of nearly 20 feet, and the space dividing it from the inner rubble bank was filled in with clay, when suddenly, without the slightest warning, the outer bank slipped forward towards the estuary for

A Bank "slides."



SECTION OF CANAL—POOL HALL BAY.

a distance of fully 150 feet, and the clay hearting followed in its wake. The cause of the "slide" was found to be the old bed of a stream which had disappeared, leaving only deep mud behind.

SLUICES BETWEEN CANAL AND RIVER MERSEY OPPOSITE INFALL OF RIVER WEAVER.

(*Photo, R. Banks.*)

Sheet-piling driven.

To prevent further slipping of the bank under the weight that remained to be added, a row of sheet-piling was driven at the back of the outer rubble toe, and between the rubble and the clay hearting, the tops of the piles being tied back to anchor-piles driven down through the clay hearting to the solid ground beneath. In this way the outward movement of the bank was arrested.

Another Source of Perplexity.

Immediately afterwards the engineering staff were confronted by another source of perplexity. Questions at issue with the Mersey Conservancy as to certain tidal openings in the embankments remained to be settled. The tipping over the site of the opening was stopped at the height of a 14 feet tide—the level of the proposed opening—and consequently this portion of the embankment was submerged at every tide. At a later date (1890) application was successfully made to Parliament for power to reduce the number of the tidal openings, which were abandoned altogether, and permission was given for the space left

BARTON LOCKS. (*Photo, R. Banks.*)

therefor to be filled. Meanwhile the hearting had become sodden and covered with mud, and when fresh clay was tipped over it forced the soft clay and mud over the tops of the rubble banks on either side. The soft clay on the slopes had therefore to be cut back and replaced by rubble.

Gradually the embankment reached the desired height across the full width of the bay; and when it was seen to stand the test satisfactorily, an opening through which the tide had ebbed and flowed during the process of building was closed. A timber viaduct was temporarily carried across the gap, and tipping operations began at low water, when the inner area was dry. This work was completed before the tide again flowed.

Embankment carried across Pool Hall Bay.

Simultaneously, the facing of the outer slope of the embankment went on. The sandstone obtained from the rock cuttings of the Canal served excellently for the purpose.

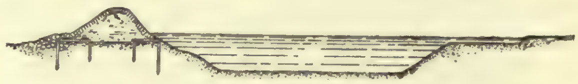
During the excavation, pockets of sand were found below the clay, and through one of these water forced its way under the embankment into the cutting. When the first "blow" made its appearance, sand and water accumulated in the cutting in quantities sufficient to interrupt operations, and the portion of the embankment directly affected indicated a settlement of between two and three feet. It was then decided to take borings along the base of the inner slope, in order that the full extent of the sand-pockets might be ascertained.

Operations interrupted.

The examination showed that protective measures were demanded for a distance of 860 feet. Accordingly a row of sheet-piling was driven in a line, 15 feet away from the base of the inner slope. "This," said Mr. Eliot, "completely stopped the settling of the embankment, and reduced the run of water to a mere soakage."

The second embankment, erected across Ellesmere Port Bay, differed from the others in that its main portion was not called upon to exclude tidal waters during construction, but only to retain the water in the Canal when the whole work had been finished. From end to end this embankment is 6,200 feet long. In the middle of the bay stands the little town of Ellesmere Port, with the docks through which the canal of the Shropshire Union Company have access to the Mersey estuary. Hence the prevailing conditions necessitated treatment of an exceptional character. Many interests had to be protected, and it was not without some bold experiments that the best means of carrying out the work were found.

The Second Embankment.



SECTION OF CANAL AT ELLESMERE PORT.

Thirteen thousand piles, each 12 inches square and 35 feet long, had to be driven, by means of a water jet, through the sand-bank facing Ellesmere Port. The sea-wall itself, 6,200 feet long and 12 feet wide, was formed with clay hearting protected by heavy blocks of stone laid on rubble backing and faced with heavy masonry. A little beyond Ellesmere Port the river Gowy is carried under the Canal by two cast-iron siphons, 400 feet in length and 12 feet in internal diameter. Sluices are provided to scour out any deposit that might accumulate, but the work is so successful that the flow of the river keeps both siphons clear.

Thirteen Thousand Piles driven.

The third embankment, constructed across Ince Bay, is 5,900 feet long, and its height averages 18 feet above the original surface of the ground. At the east side, for a distance of 3,400 feet, the embank-

The Third Embankment.

ment is 30 feet wide; but on the western side, over a length of 2,500 feet, the width is reduced to 20 feet. Here the ground consisted of very soft mud and silt, which extended below the bottom of the Canal cutting. The engineers were convinced that the ordinary section of embankment, with an inner slope of 1 to 1, carried down to the bottom of the Canal, would never rest upon such a foundation.

A row of sheet-piling was therefore driven along the line where the inner slope cut the surface of the mud, and the width of the embankment was reduced so as to add nine feet to the width of the slope from the top of the sheet-piling to the bottom of the Canal, the whole of this slope being formed of rubble.

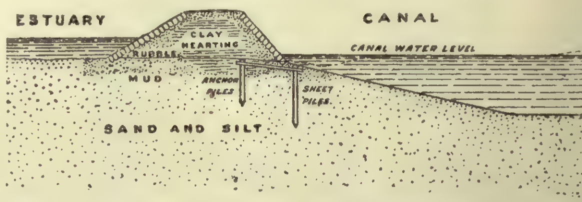
Soft Mud and Silt to be dealt with.

The soft mud, extending to a depth of four or five feet, was taken out of the space between the sheeting and the rubble. In its place clay was tipped to form the heart of the bank, and simultaneously faced on both slopes with rubble. But when the excavation for the Canal began, the ground was so soft that the top of the sheet-piling gave way towards the cutting. In these circumstances, the centre line of the Canal had to be removed for a certain distance landwards, so as to allow of a slope of 4 to 1 from the top of the sheet-piling to the bottom of the cutting. This arrangement proved effective, and the formation of the embankment was continued.

Centre Line of Canal changed.

In the next (centre) section sandstone rock lay at the foot of the inner slope, close to the surface of the mud. Here a trench nine feet wide and about nine feet deep was formed in the mud by means of a Priestman grab, and filled in with rubble, to form a footing for the outer slope of the embankment. The rock on the inner slope, being soft in places, was liable to be scoured away, and the precaution was adopted of introducing a brickwork facing to that portion of the rock.

A Trench in the Mud.

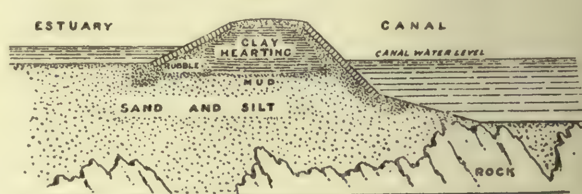


INCE BAY EMBANKMENT (WEST SECTION).

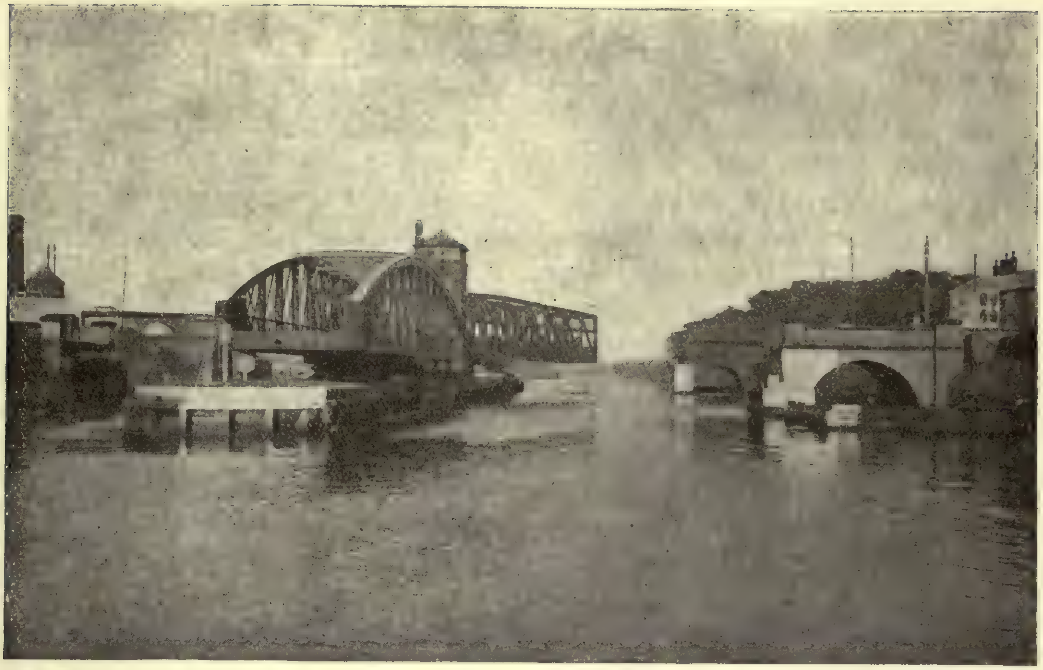
For a distance of 1,400 feet the foundation for the eastern section of the embankment consisted of sand, with an upper layer of soft mud. This formation necessitated a different method of procedure; and in order that the weight might be kept down as much as possible until the excavation had advanced sufficiently to permit of the inner slope being formed, the boulder clay was not in the first instance tipped to the full height of the bank on the outer slope. The sand was very wet, and the excavation at the back had to be carried out with extreme care. Gradually the sand was drained, and it then became safe to place rubble on the slope,

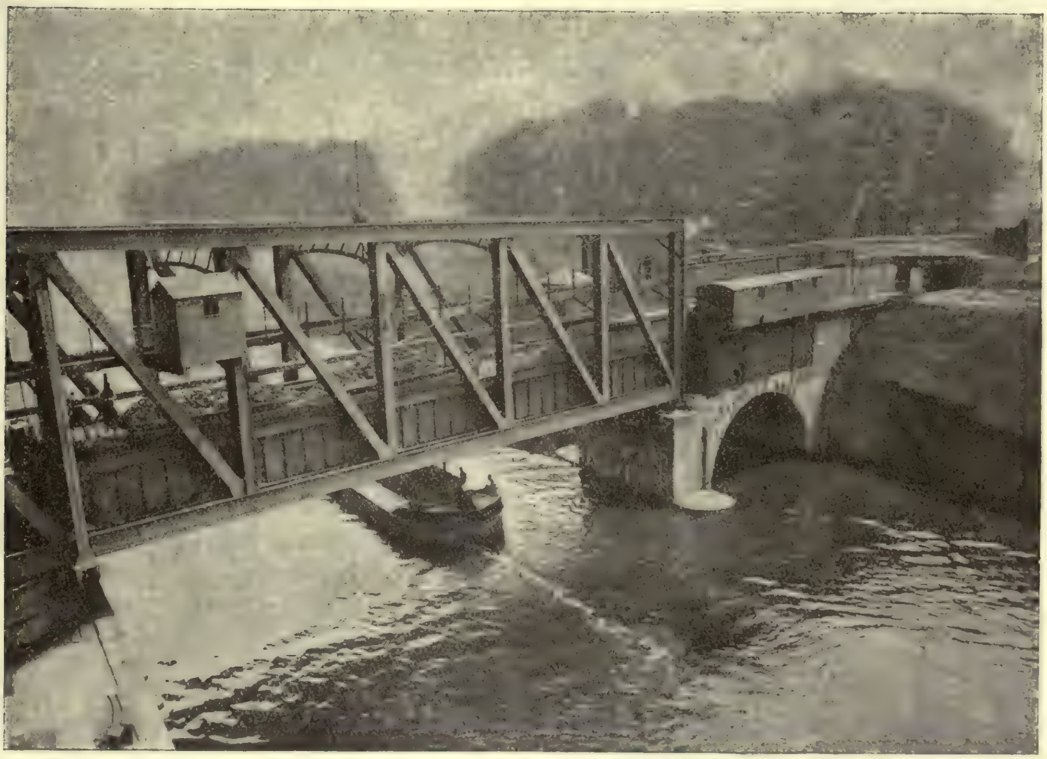
A Different Method used.

INCE BAY EMBANKMENT (CENTRE SECTION).



INCE BAY EMBANKMENT (EAST SECTION).





(*Photos, R. Banks.*)

BARTON SWING ROAD-BRIDGE AND AQUEDUCT.

1. Open to allow a ship to pass. 2. The aqueduct closed to allow Bridgewater Canal barges to pass over the Ship Canal.

and to continue it to the top of the embankment.

Strong Gales.

This section was, during the prevalence of north-westerly gales, continually exposed to rough weather, and several times the rubble was displaced before it could be protected by the heavy stone pitching. Consequently it was resolved to deposit rough blocks of stone, which were afterwards dressed to form the pitching.

Abnormal Tides.

Like that in Pool Hall Bay, this embankment had not only to retain at low tide the water in the Canal when completed, but also, during construction, to exclude the tidal water of the estuary from the cuttings. Both had therefore to be thoroughly water-tight, so that, even when agitated by a storm, the estuary water might not be forced through or over the top of the embankment. These precautionary measures proved essential, inasmuch as tides rose very high during gales of wind, and on one occasion attained a height of seven feet above the maximum point expected.

Canal opened to the Weaver Sluices.

From the sluices of the river Weaver to No Man's Land at Runcorn an embankment, 14,100 feet in length, had to be constructed, and thence a concrete wall, 4,300 feet long, was carried to Runcorn Lock. A lock was provided at Weston Marsh to give an entrance from the Ship Canal to the Weaver Navigation; and when a dam had been put across the Canal just above the Weaver sluices, the Canal was complete from the dam to Eastham—four years after the contract had been let. The Weston-Mersey Lock, which was fitted with five pairs of gates, was completed in twelve months, which was regarded as the shortest time on record for a lock of its size.

Good Work done.

Locks of similar width (45 feet) were constructed at the entrance to the Bridgewater Canal, and also at Runcorn; and in commenting upon the embankments and locks generally, Sir E. Leader Williams acknowledged that praise was due to the contractor "both in regard to rapidity of execution and to the good quality of the work."

Provision for Tall-masted Ships.

Immediately below Runcorn Docks there is a lay-by, 1,500 feet long, with a depth of 28 feet of water alongside, equipped with salt tip, movable cranes, and other appliances. Sailing vessels, whose lower masts, after striking topmasts, are too high to enable them to pass under the fixed bridges, are here berthed, so that their cargoes may be discharged overside, and lightered to Manchester, without any extra cost to the importer beyond the Canal toll.

SECTION OF CANAL AT RUNCORN.

Runcorn Docks.

The Runcorn Docks, to which the Bridgewater Canal Lock forms the entrance, are used extensively for export and import trade. For a length of 1,500 feet the quays have a frontage to the Ship Canal.

The Canal turns inland.

From Runcorn to Latchford the Canal runs inland, on what is approximately a straight course, the tidal influence ending at the locks at the latter place. A cutting three miles long connects the tidal portion of the Canal with the river Mersey, which, to its confluence with the Irwell, has been absorbed in the more direct course pursued by the Canal. The Manchester system of docks begins at Mode Wheel. Below these, for a distance of two miles, the bottom width of the Canal increases from 120 feet to 170 feet, allow-

A SAILING SHIP AT ELLESMERE PORT.
(*Photo, K. R. Burgess.*)

ing vessels to remain at wharves loading or discharging without interfering with the passage of traffic in the fairway. The total rise on the Canal above the low-water level below Latchford Lock is about 59 feet, which gives an average of under 15 feet for each set of locks.

Excavation Work.

The Canal excavation amounted in all to about 54,000,000 cubic yards, including 12,000,000 cubic yards of sandstone rock; and the rate of excavation varied between 750,000 and 1,250,000 cubic yards per month.

Number of Men and Boys engaged.

Owing to the very extensive plant employed, the number of men and boys engaged never exceeded 17,000. The length of the single lines of railway temporarily laid down was 228 miles, and the rolling stock consisted of 173 locomotives, with 6,300 wagons and trucks. There were 124 steam-cranes and 192 fixed or portable engines, used chiefly for pumping. The total cost of the plant employed in construction was £980,000.

Cuttings damaged by Floods.

As the upper portion of the Canal was excavated along the valleys of the Irwell and Mersey for a distance of 20 miles, a channel had to be kept open for the flood and ordinary waters of those rivers, which were intersected in thirty different places. But notwithstanding all expedients, floods twice caused serious damage to the slopes of the cuttings. In November 1890, 13 miles of the Canal were prematurely filled, and in December 1891 flood water rushed into 10 miles of the cutting. Both disasters inevitably entailed considerable additional expenditure as well as great delay.

Railway Crossings.

Five important railways cross the Canal, and deviation lines, each about two and a half miles long, had to be laid with gradients sufficient to allow a clear headway under the viaducts of 75 feet at ordinary water-level. The Runcorn Viaduct, previously constructed across the Mersey, gives that headway at high water of spring tides. For unimportant roads and footpaths, ferries on the Canal have been adopted.

Swing Bridges.

There are also seven swing bridges, five of which have a clear span of 120 feet. Eight hydraulic installations are provided, each with duplicate engines and boilers, to work the cranes, warehouse lifts, the capstans at the docks, the coal tips at Partington, the lock gates and culvert sluices, and several of the swing bridges.

PART OF RUNCORN RAILWAY BRIDGE AND RUNCORN TRANSPORTER BRIDGE. CONCRETE EMBANKMENT ON LEFT. (*Photo, K. R. Burgess.*)

HIGH-LEVEL FOOTBRIDGE AT WARBURTON.
(*Photo, K. R. Burgess.*)

The Barton Canal Aqueduct called forth a bold device on the part of the engineers. Brindley's Aqueduct, to which reference has been made, was built of stone and brick. There were three arches, and the canal carried was 18 feet wide and 4 feet 6 inches deep. The difference in level between the Bridgewater Canal and the Ship Canal at Barton being 26 feet, a movable aqueduct was essential.

The Barton Canal Aqueduct.

Basing his calculations upon the success that had attended the operation of a lift on the Weaver Navigation—where he had himself utilized hydraulic power to lift boats 51 feet vertically to another navigation, while they remained floating in an iron trough—Sir E. Leader Williams planned a new aqueduct, spanning two openings each with a width of 90 feet on the Ship Canal, and a waterway for the Bridgewater Canal 19 feet wide and 6 feet deep.

The Movable Spans.

This aqueduct rests and turns upon a central pier 400 feet long and 30 feet wide, which carries also the adjacent road swing bridge. Water-tight iron gates are supplied at each fixed shore-end, and also at each end of the trough. When the four gates are open, barges move along the Canal without interruption. But if a ship has to pass under the aqueduct all the gates are closed—the shore gates keeping back the water in the Bridgewater Canal at either side, the others confining the water in the trough when it is turned through an angle of 90° for the passage of a vessel along the Ship Canal.

Water-tight Iron Gates.

The trough can be swung when the barges are inside, the gross weight to be moved always remaining the same. Power is obtained from the adjoining hydraulic station, which is also employed for the road swing bridge, both being operated from a high brick tower. Sir E. Leader Williams devoted particular attention to the whole of this arrangement, and the members of the Institution of Civil Engineers were delighted when he informed them that the aqueduct "has never given any trouble, working quickly and with smoothness—a result for which much credit is due to the contractors, Messrs. Handyside and Company."

A Successful Arrangement.

Wharves have already been constructed at Runcorn, Warrington, and other places; and as the Canal really consists of a series of long, narrow docks, this accommodation may at any time be extended almost indefinitely.

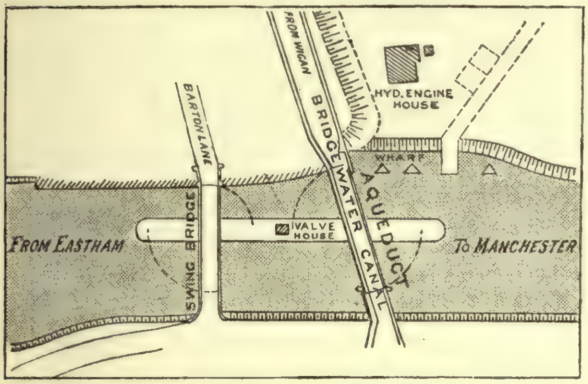
Wharves.

At Ellesmere Port, the terminus of the

IRLAM HIGH-LEVEL RAILWAY BRIDGE.
(*Photo, K. R. Burgess.*)

Ellesmere Port.

Shropshire Union Railways and Canal Company, quays, with coal tips and sheds, have been provided. The navigations of this company extend to Cheshire and through Shropshire, while, by junctions with other waterways, they enter many industrial districts, including those of North and South Staffordshire.



PLAN OF BARTON SWING AQUEDUCT AND SWING BRIDGE.

In addition to their own docks, the same company have wharfage fronting the Canal, and two leading railways have direct access thereto.

Dry Docks.

Quite close at hand are the pontoon dock and repairing yards of the Manchester Dry Docks Company, Limited, which has more extensive premises with dry docks and other facilities for dealing with large steamers near Mode Wheel locks—a duplicated arrangement much appreciated by shipowners.

Partington Coal Depot.

The Partington coaling basin is admirably situated in respect alike of rail and water communication. It has brought thirty miles nearer the sea the immense coalfield of South Yorkshire, which geologists regard as practically inexhaustible, and it is likewise close to the Lancashire coal-bearing areas. The coaling basin forms part of the Canal, and vessels can therefore remain at the tips without causing the least interference with the ordinary traffic. There are already six tips in use, each delivering about 160 tons per hour; and there are foundations for another tip, which can be erected whenever it may be needed. Containing on an average 10 tons of coal, the loaded wagons are run in at the level, raised to the mouth of the shoot, tipped, and returned, by gravity, along an overhead incline.

Imported Live Stock Depot.

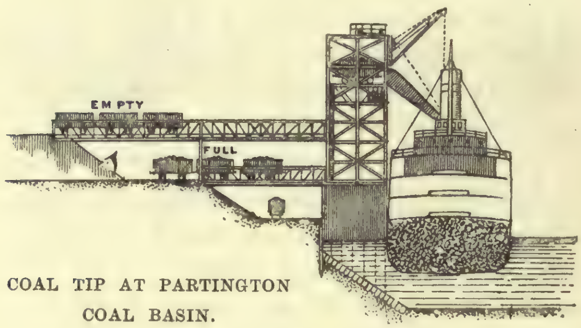
At Acton Grange another tip deals with coal brought by rail in specially-designed boxes, which are loaded into steamships simultaneously with general cargo; while at Weaste (just below the Mode Wheel locks) a special crane lifts wagons bodily loaded with coal, swings them over, and discharges them into a steamer at one operation. On the other side of the Canal, below Mode Wheel Lock, the Manchester Corporation has timber wharves, and a foreign animals depôt, covering 12 acres of land. The site is admirably suited for the purpose, and accommodation exists for 3,000 head of cattle. There is a continuous landing-stage upon which cattle may be discharged by means of movable gangways. At this point the Canal is 300 feet wide. The appliances include refrigerating, electric lighting, and pumping plants, which make the depôt one of the most complete in the country. Extensive cold stores not far away have also been opened by the Corporation.

Oil Tanks.

The activity of the same municipal authority has been manifested in regard to another industry, which has in recent years attained vast proportions—namely, that which provides lubricating and illuminating oils. On the banks of the Canal, immediately adjoining the foreign cattle depôt, the Gas Committee of the Corporation have built extensive oil tanks, and their example has been followed elsewhere by the British Petroleum Company, Limited, the Anglo-American Oil Company, Limited, and

others, which are now reaping the full advantage of their enterprise.

Already the Manchester Dock Estate covers an area of 406½ acres, including a water space



COAL TIP AT PARTINGTON COAL BASIN.

of 120 acres, with quays 6½ miles long and 286½ acres in extent. There are eight docks in existence, and a site, in a splendid position, has been reserved for another dock of large dimensions. The largest of the present range, occupying a portion of the old Manchester racecourse, is 2,700 feet long, 250 feet wide, and 28 feet deep. It has a water area of 15½ acres, and with its transit sheds and railway sidings cost nearly £500,000. Here, as over the Dock Estate as a whole, the equipment is in every detail of the most approved character, giving the port the highest position in regard to the rapid handling of every class of goods.

Manchester Dock Estate.

The entrance lock at Manchester opens into a turning basin more than a quarter of a mile wide, giving access to three branch docks, from 250 to 225 feet wide, with intervening quays 263 feet wide. From the turning basin the Canal is continued to the Irwell above Trafford Road. There the river has been widened to 200 feet, with a view to securing an adequate approach to the upper docks, which have four arms, from 120 to 150 feet wide, provided with sheds and lines of rails.

The Turning Basin.

All the railways in Manchester are now connected with the docks. The dock lines and sidings alone exceed 80 miles in length; and before the Canal had been opened three years, the railway traffic in and out averaged 2,500 trucks per week. In addition a large volume is dealt with by the fourteen independent canal systems in communication with the Ship Canal. Together, these serve 750 square miles of country, and furnish a valuable link in different water routes such as does not exist in any other part of the United Kingdom.

A Valuable Link in our Waterways.

The hearts of the promoters thrilled with joy at 10.30 p.m. on November 25, 1893, when they were able to announce to the world that every section of the Ship Canal was full of water. A month later the Lords Commissioners of the Treasury issued the warrant constituting Manchester a harbour and port for Customs purposes; and on January 1, 1894, the Canal was opened for traffic, the event being celebrated by the entrance into the docks of no fewer than seventy-one vessels of large and small tonnage.

The Canal filled with Water.

This was, indeed, an auspicious beginning, and its significance was emphasized by the State ceremonial with which Queen Victoria, on May 21 following, inaugurated the magnificent enterprise. On that occasion her late Majesty uttered words which will never be forgotten:

Queen Victoria opens the Canal.

"The immense undertaking which I have this day opened has filled me with admiration. Exceptional engineering as well as other difficulties have been overcome, and the commerce of the world has been brought into direct communication by sea with your great city and its neighbourhood."

Many improvements have since been effected, chiefly in the direction of increasing the terminal facilities at the docks in Manchester, and it is now claimed that the Canal affords one

of the best means of cheapening the cost of transit on all descriptions of traffic from the manufacturing centres of Lancashire, Yorkshire, and the Midlands.

Cheaper Transport.

One result of the changes witnessed since 1894 has been the conversion of the terminal docks into what is really a prodigious waterside railway goods station, every dock, basin, warehouse, and shed included in the system being furnished with one or more lines of railway. A grain elevator, with storage capacity for 40,000 tons (1,500,000 bushels), has long been in successful operation, and a second is to be erected.

Huge Waterside Goods Station.

The port serves the most densely-populated district in England, and the Canal has been navigated up to Manchester by vessels of 12,000 tons dead-weight capacity. Some of the largest ocean-going steamships are, in fact, regularly navigating its waters, under conditions of absolute safety.

Capacity of the Canal.

Since the opening of the Canal, the total tonnage in traffic and the total yearly revenue have been :—

Year.	Tons	£
1894.	925,659	97,901.
1895.	1,358,875	137,474.
1896.	1,826,237	182,330.
1897.	2,065,815	204,664.
1898.	2,595,585	236,225.
1899.	2,778,108	264,775.
1900.	3,060,516	290,830.
1901.	2,942,393	309,517.
1902.	3,418,059	358,491.
1903.	3,846,895	397,026.
1904.	3,917,578	418,043.
1905.	4,253,354	449,436.
1906.	4,700,924	498,837.
1907.	5,210,759	535,585.
1908.	4,582,496	506,975.

Up to the present time the expenditure on capital account has been nearly £17,000,000.

A record such as that disclosed by these figures proclaims the success of the Canal. It could not be expected that the sanguine expectations of its brave promoters should be fully realized in the comparatively short period that has elapsed since the venture was consummated. But wonderful progress has been achieved. Mr. W. H. Hunter, who is now the chief engineer, declared, in a paper read at the International Engineering Congress in 1904, that "the operation of the Manchester Ship Canal has directly or indirectly affected beneficially the whole of the greatest industrial district on the face of the earth—a district of which the present population does not fall far short of 10,000,000 persons—while in the more limited area, of which the city of Manchester is the heart and centre, many industries have been saved from extinction, and many others from decline and ultimate decay."

Success of the Project.

Ten Million People benefited.

Between the years 1880 and 1890 "it was only too apparent," said Mr. Hunter, "that in Manchester and its environment of manufacturing towns decadence was stamped upon almost every industry, and that all progress was arrested. One manufacturer after another moved his works to the seaboard, leaving disused factories, empty warehouses, and uninhabited dwellings. . . . Now, not only has decline been arrested and decay averted, but lines of new and vigorous growth have shot, and are shooting, out on every side. North, south, east, and west, there is no exception—expansion is universal. Old industries have been revived, and new industries have been introduced. The change is definite and impressive, and has been due solely to the effect and influence of the Canal."

Decline of Trade arrested.

In the same paper Mr. Hunter quoted a very remarkable statement by Mr. C. W. Macara, President of the Federation of Master Cotton Spinners' Associations, and ex-President of the Manchester Cotton Association, that "the Canal has, in reduction of the cost of conveyance of raw cotton and of goods manu-

factured therefrom, been worth at least £500,000 to the cotton trade alone." There is no greater authority on the staple trade of Lancashire than Mr. Macara, and the conclusion at which he arrived is confirmed by Sir Frank Forbes Adam, formerly the President of the Manchester Chamber of Commerce, which has

Immense Savings in the Cotton Trade.

A LONG SHOOT DREDGER. (*Photo, Messrs. Lobnitz and Company, builders of the dredger.*)

two thousand members representative of the principal towns and trades in a radius of twenty miles round Manchester.

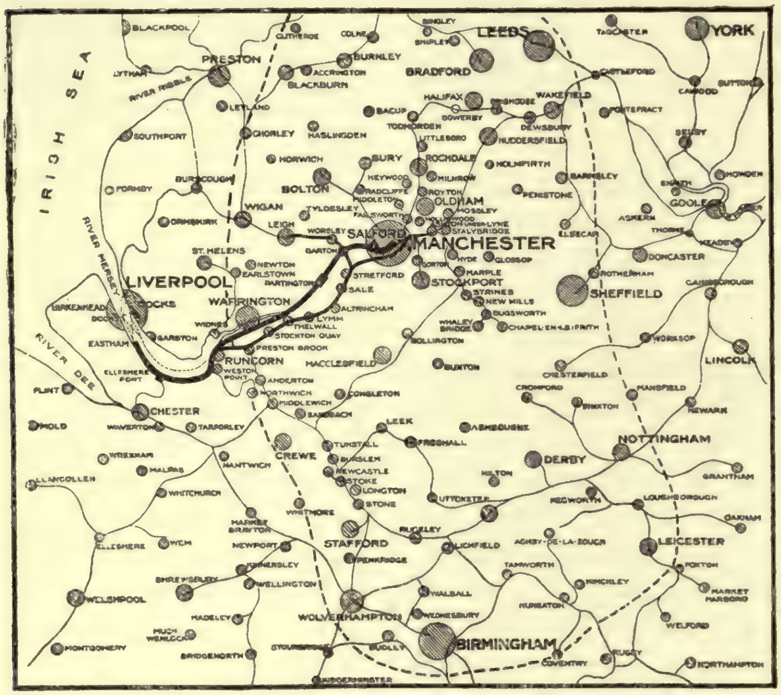
Manchester as an Importing and Exporting Centre.

In an interesting contribution published in the *Journal of the Royal Geographical Society* of November 1908, Mr. John M'Farlane, Lecturer in Geography at the University of Manchester, gave an account of the position which that city now holds as an importing and exporting centre. He showed how the grain trade had developed between the years 1895 and 1907; and, in allusion to the fact that the port has already become an important fruit-distributing centre, pointed out that, of the bananas shipped to England from the West Indies and Costa Rica, two-thirds are landed in Manchester, the remainder going to Bristol.

Mr. M'Farlane frankly acknowledged that the port of Manchester is at present handicapped by economic and commercial considerations, "largely the result of the momentum which the older ports, and more especially Liverpool, have acquired." But he did not believe that this state of things will be permanent. "Manchester," he confidently predicted, "will acquire a momentum of its own, which will enable it to overcome the difficulties with which it is surrounded, and transform it into one of the leading ports of the kingdom."

One of the Great Ports of the Future.

To Sir E. Leader Williams belongs the chief credit for the remarkable engineering triumph which the completion of the Canal records. Closely associated with him, and ever performing most valuable work, has been Mr. W. Henry Hunter, his successor as chief engineer. Mr. Ernest Latimer is the general superintendent, Mr. H. M. Gibson chief traffic superintendent, and Mr. F. A. Eyre secretary of the Manchester Ship Canal Company.



MAP OF DISTRICT SERVED BY THE MANCHESTER SHIP CANAL EITHER DIRECTLY OR THROUGH ALLIED CANAL SYSTEMS.

NOTE.—*For the plans and sections, as also for much information, the writer is greatly indebted to Mr. J. K. Bythell, the chairman of the Ship Canal Company, and also to Mr. H. Hunter.*

The Construction of Fishguard Harbour

BY FELIX J. C. POLE.

ONE of the most recently constructed harbours in the United Kingdom is that of Fishguard, on the north coast of Pembrokeshire, the terminus of the main line of the Great Western Railway from London to South Wales. This harbour is noteworthy not only for the magnitude of the engineering work involved in its formation, but also as typifying modern tendencies in regard to what may be termed the location of an ideal port of call. When transit on land was slow and difficult, it was essential that ports should be as far inland as possible in order that they might form distributing centres. With the development of railways, however, it was clearly desirable that ports should be located at such points as were most accessible to the huge modern liners, and be connected by railways with the various centres of population, the reduction of time in the railway journey as compared with that of transit by water being a valuable asset.

A Notable Port.

These advantages apply in a very great degree to Fishguard; for while primarily constructed as a link in a new short route to Ireland, the promoters had in view the possibilities of the place as a port of call for Atlantic liners, and already the harbour is used by one important line of South American steamers.

In view, therefore, of the importance which the place is likely to have in the near future, it may be well, before proceeding to describe the engineering features, to give a few brief particulars regarding Fishguard and the scheme in connection with which the harbour was constructed. Fishguard Bay is situated on the northern coast of Pembrokeshire, south of Cardigan Bay—a place of historic interest as the scene of the last invasion of British soil. This occurred in 1797, when a French force effected a landing, but retired before a body of Welsh militia under Lord Cawdor. The story runs that the credit of the victory must be shared with the fair sex, the women of the neighbourhood in their national red mantles and beaver hats having been mistaken by the Frenchmen for British soldiers, when, in accordance with Lord Cawdor's strategy, they marched down a slope in close order, disappeared at the bottom, ascended from the other side and repeated the manœuvre, the result being that the Frenchmen were disheartened by the apparent strength of the force opposed to them, and surrendered without striking a blow.

Fishguard Bay.

THE SITE OF THE HARBOUR AS IT APPEARED A HUNDRED YEARS AGO.

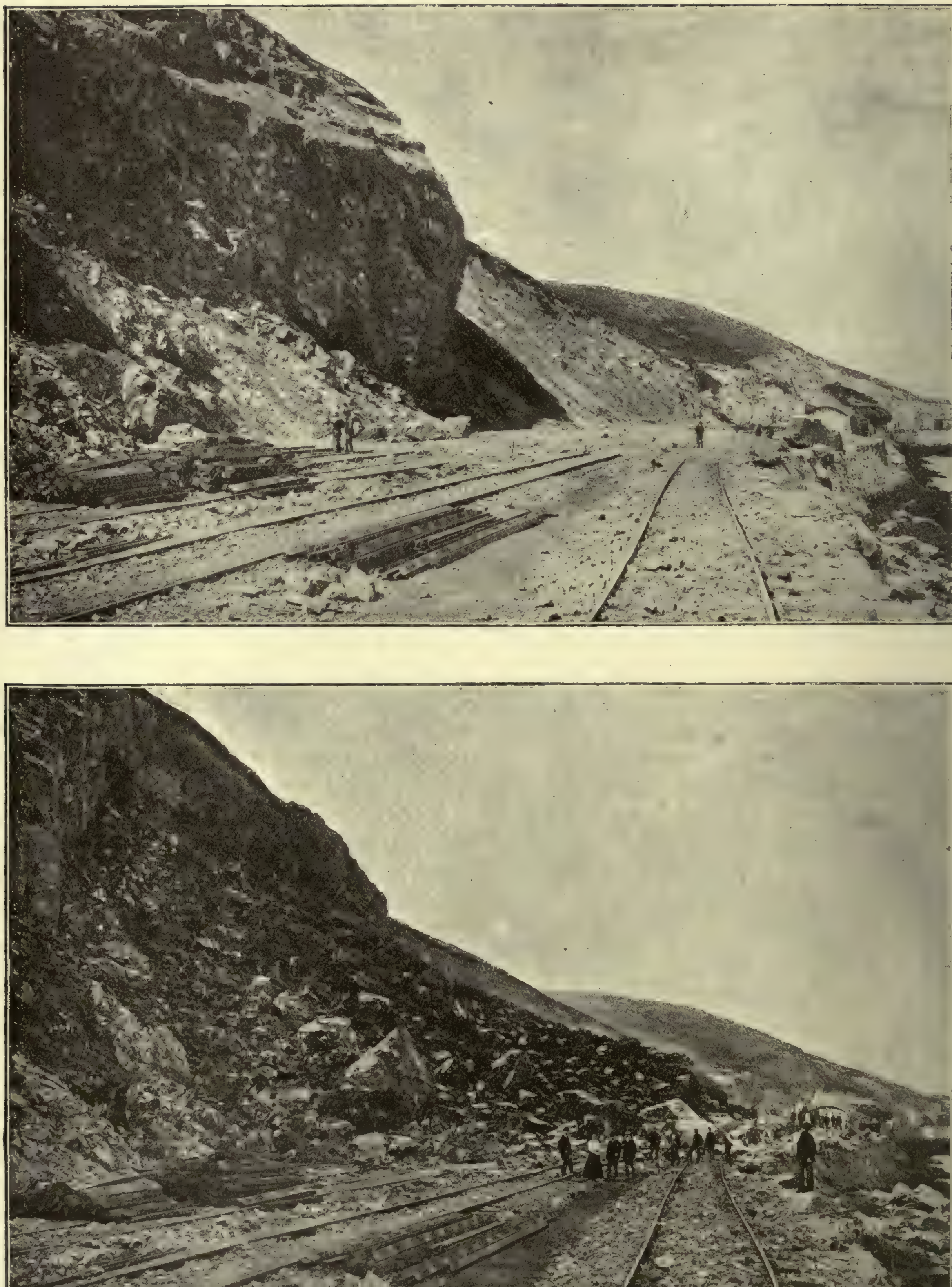
Whether this story be historically correct or not, it is certainly the case that towards the end of the eighteenth century the Lords of the Admiralty regarded Fishguard as a highly suitable place for the construction of a secure harbour. A report obtained by them set out that, were a proper pier made at Fishguard, all ships in the south part of the Irish Channel, when forced by southerly or westerly gales to bear away to a harbour, might safely run for Fishguard Road, if they could not fetch Milford; while packets from Waterford would have the advantage of the choice of two ports, for if the wind were so strong from the south as to make it difficult to reach Milford, they could easily put into Fishguard, which afforded shelter from south and south-east winds. "Should the wind suddenly shift to the north-east while they were in Fishguard Bay, they would have only to run to the proposed pier at Fishguard, where they would be safe from all winds and weather."

Its Suitability for a Harbour.

The proposed "pier" would seem to have been of the character of the breakwater since constructed; but nothing came of the scheme, nor of a further one put forward in the year 1845, when a railway was planned to run through South Wales. The engineer of that line was Isambard Kingdom Brunel, and by him the advantages of Fishguard Bay were recognized, the western terminus of the proposed railway being located at Fishguard, whence a line of steamers was to run to southern Irish ports. The line was sanctioned by Parliament, and its construction commenced; but the depression following the "railway mania" of the 'forties, and the financial difficulties that subsequently beset

Brunel's Scheme.

THE SITE AS IT APPEARS TO-DAY.



BLASTING THE CLIFFS.

Views before and after the Explosion.

the South Wales Railway, caused it to be stopped west of Swansea, and it was finally diverted to Milford instead of to Fishguard.

Almost exactly fifty years after the inception of Brunel's scheme there was a revival of interest in Fishguard. In 1893 the Fishguard Bay Railway and Pier Company obtained Parliamentary powers to provide a harbour and run a service of steamers to Rosslare on the Irish coast. Other proposals were made subsequently, but ultimately the scheme was taken over by the Fishguard and Rosslare Railways and Harbours Company—a combination of the Great Western Railway (England) and the Great Southern and Western Railway (Ireland) Companies, the former of which became responsible for the works at Fishguard.

A Modern Scheme.

A TYPICAL EXPLOSION.

Observe that a huge mass of rock on the right has been lifted bodily several feet.

Work to be done.

Fishguard Bay is a grand expanse of water opening to the north. The distance from east to west is about 3 miles, and from north to south $1\frac{3}{4}$ miles. Its general depth of water varies from 30 to 70 feet, and it is sheltered on three sides by hills rising to a height of some 300 feet. The point selected for the harbour was on the western side of the bay. There the sea washed against the base of precipitous cliffs, and it was necessary to slice away the rock to form a terrace for the harbour station and railway; while to render anchorage safe at all times a breakwater had to be thrown out from the shore for a length of 2,000 feet.

Excavating Rock.

The start was difficult, as cliffs from one hundred to two hundred feet high represented the ground to be worked upon. Moreover, as these cliffs were of an intensely hard, vitreous rock, excavation could be effected by explosives only, the boring of holes to admit of the insertion of charges being done entirely by hand. In many cases the men had to be slung by ropes from the top of the cliff. To add to the difficulties, the nearest railway station was at Letterston, seven miles away, whence all machinery, cranes, etc., had to be conveyed. Even the first locomotives reached the works in this way, traversing a steep road *en route*. When sufficient rock had been removed to form a convenient ledge, an installation of pneumatic drilling plant was put down, and blasting operations were pushed on rapidly. Two methods were adopted for dislodging the rock. The first was to bore holes up to 20 feet deep and $2\frac{1}{2}$ inches in diameter, charge them with from 20 to 50 lbs. of gelignite, and fire the charges by electricity. The second method, employed where the cliffs were high, was the explosion

of large mines of gunpowder. A tunnel of about forty feet long having been driven square into the face of the cliff, cross-headings were run from the end so as to form a T-shaped excavation. The ends of the cross-headings were then chambered out to accommodate from seven to ten tons of gunpowder, which was ignited electrically after the tunnels had been securely built up. Some of the largest mines of this kind tore off enormous masses of rock, the displacement at times being upwards of 100,000 tons. Blasting operations were carried on for some four years, in which period more than 2,000,000 tons of rock were dealt with, the result being that an area of about 27 acres was made available for railway purposes, partly by removal of the cliffs and partly by tipping material out from the shore. The excavation was carried to a maximum depth into the cliff of 180 feet, and to a height of 200 feet for a distance of more than 600 yards. On ground thus formed have been constructed an extensive quay, a railway station, an electric generating station, offices, and general equipment of an up-to-date port.

Great Blasts.

The exact form of the harbour and buildings is best shown by the several illustrations, reproduced by the courtesy of the Great Western Railway, and therefore this description will be confined to the broader details of construction; for it must be remembered, when considering the engineering features of a port, that the magnitude of its works, in the form of breakwaters, quays, etc., is probably ten times greater under water than above.

Simultaneously with the excavation of the cliffs, the construction of the breakwater and other works proceeded. The rock blasted down was loaded by steam travelling cranes into tip wagons, and conveyed over temporary railway lines to the various parts of the works. By far the greater part of the material was required for the breakwater, the seaward side of which was faced with boulders weighing from three to fifteen tons. Stones of from one hundredweight to three tons in weight formed the harbour side of the breakwater, or were tipped to extend the space for quay and sidings. Stones of less than a hundredweight were crushed for ballasting the railway lines, while the small chippings afforded material for making concrete blocks for the quay wall. Thus nothing was wasted.

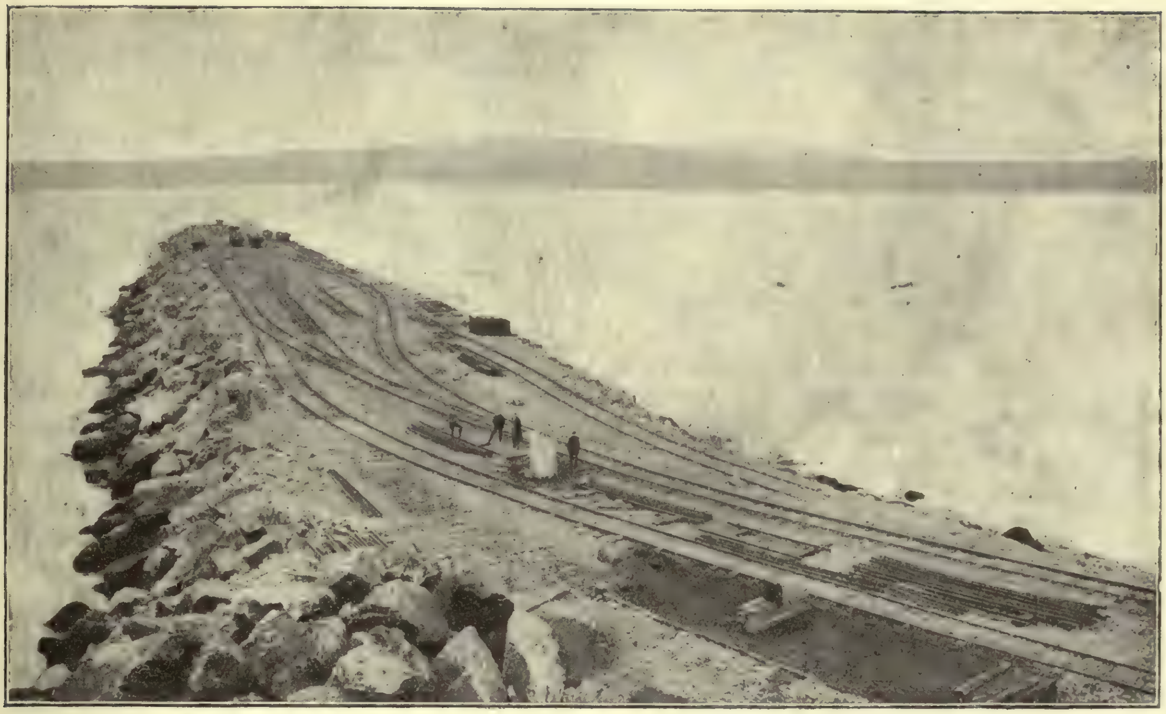
The Breakwater.

The breakwater, a huge mole 300 feet wide at its base and 70 feet at the top, rises about 70 feet from the sea-bed. On an average some 650 tons of stone had to be tipped for each foot of its total length of 2,000 feet. It shelters an area of 500 acres, and its top—20 feet above sea-level—is capped by a concrete parapet.

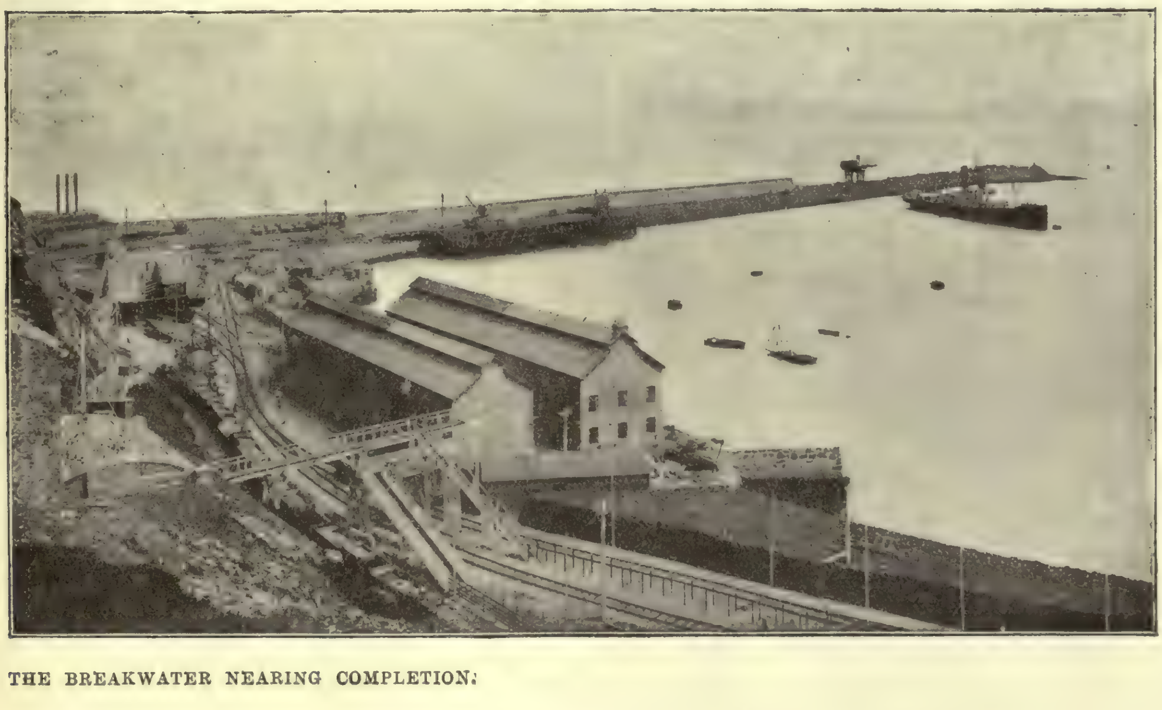
At the present time quay space of over 1,110 feet provides berths for three vessels, the minimum depth of water alongside being 20 feet. The quay wall is by no means the least interesting feature of the works. From its foundations, where it is 19 feet 6 inches thick, it rises 50 feet, and in its construction some 5,000 concrete blocks, each weighing from 6 to 11 tons, and manufactured on the site, were used. To secure firm foundations a trench was excavated by a suction dredger; a grab hopper barge followed, taking off the shingle down to the rock, which was then levelled by divers, any hollows being filled up with concrete in bags. In this way was obtained a perfectly level foundation, upon which a "Titan" crane was able to lower and set accurately the blocks—each of which had previously been allowed a period of three months to "mature" after the time of its manufacture before being placed in the wall.

The Quay Wall.

The quay wall was built of blocks to within three feet of high water, where it was 13 feet 6 inches thick. Above the blockwork the wall is of mass concrete, shaped in casings or



THE BREAKWATER IN COURSE OF CONSTRUCTION.



THE BREAKWATER NEARING COMPLETION.

moulds. In this way a half-arch was formed in the face of the quay wall, the concrete being reinforced by old iron rails bent to suitable shape. This arch is the cattle gallery. It extends for the whole length of the quay under the passenger and cargo space, and enables cattle to be unloaded from

Accommodation for Cattle.

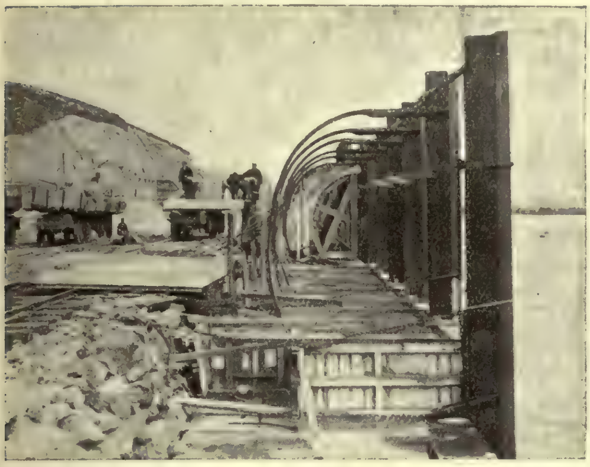
LAYING THE FIRST BLOCK OF THE QUAY WALL.

any gangway of a vessel. The seaward side is securely fenced for the protection of the animals, gates being provided at convenient intervals; while, by means of a subway connected with the gallery, access is obtained to the cattle pens at the rear of the passenger station.

The harbour railway station has platforms 800 feet long, connected with each other by a subway and an electric traverser. The accommodation includes waiting and refreshment rooms, and a special feature is that passengers proceeding from or to the vessels are entirely under cover. There are two goods platforms similar in length to those for passengers, the outer one being protected for the whole of its length and for half its width by a low roof; while the inner one, and the adjoining passenger platforms, are covered by a single span steelwork roof, 470 feet long. In all, there are eight lines of railway on the quay, and a total of six miles of running line and sidings within the harbour limits.

Quay Equipment.

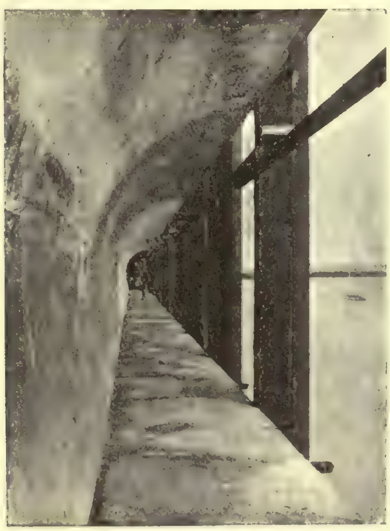
On the quay there are nine electric traversing cranes for dealing with cargo and mails, while a 21-ton stationary crane is available for heavy cargo and for coaling operations. There is also a complete installation of electric capstans for hauling vehicles into position on the quay.



CONSTRUCTING THE CATTLE GALLERY.

The curved iron rails reinforce the concrete walls of the quay.

From what has been said already it will be apparent that electricity is a motive force of primary importance at Fishguard. The lighting and heating are also electric. A generating station forms part of the equipment. Subsidiary works include extensive fitting and repairing shops, offices for the marine officials, and a group of houses for the staff. These houses have been erected on the top of the cliffs, where the Great Western Railway purchased an estate of 27 acres, part of which has been planted with 80,000 pines to afford shelter to the dwellings. On the estate a 400,000-gallon reservoir, fed by adjacent springs, provides a thoroughly efficient water supply.

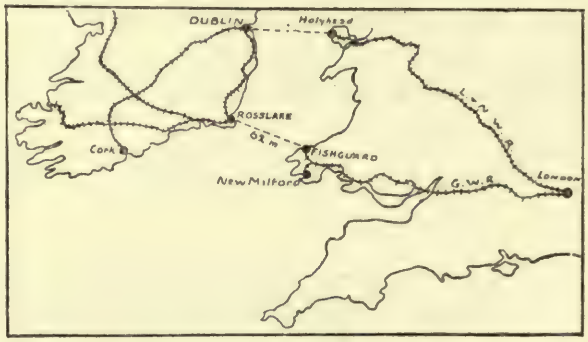


THE COMPLETED CATTLE GALLERY.

Dredging operations have been carried on in the harbour, and there is ample depth of water in all parts to accommodate safely vessels of large draught at all states of the tide.

Weather-recording Instruments.

It is claimed that the harbour is singularly free from fogs, none having occurred to interfere with access thereto during a period of three years. Another point of interest relates to the means adopted for securing reliable data as to the weather in and around the harbour. Instruments to record the hourly variations in the direction



SKETCH MAP SHOWING THE TWO MAIN ROUTES FROM LONDON TO IRELAND.

and velocity of the wind were installed on a high cliff, and the statistics for a period of two years indicated the prevailing wind to be S.S.W., or off-shore.

The Fishguard Liners.

For the Fishguard-Rosslare service—the main purpose for which the harbour was constructed—four magnificent turbine steamers have been provided, named appropriately *St. George*, *St. David*, *St. Patrick*, and *St. Andrew*. The principal dimensions are: length, 350 feet; breadth, 41 feet; depth, 17 feet 6 inches; gross tonnage, 2,500 tons. They are of the awning deck type, having lower deck, main deck, boat deck amid-

AN ILLUSTRATION OF THE DAMAGE DONE TO TIMBER PILES BY THE "TEREDO" OR WOOD-BORING WORM.

ships, and topgallant forecastle, and have been built of steel, under Lloyd's special survey, to class A1, also to the Board of Trade requirements as regards passenger steamers. The fittings throughout illustrate the most modern principles. There is accommodation for 1,000 passengers and sleeping space for 220 first and 100 second class passengers. The propelling machinery consists of three independent Parson's compound steam-turbines, developing a speed of 23 knots per hour.

In this book we are concerned with great engineering achievements, and we feel that what has been done at Fishguard may rightly be included in this category. We understand, however, that the works, considerable though they be at present, are to be very greatly extended, and that provision will be made for berthing the fastest and largest vessels afloat.

The harbour works were carried out by Mr. James C. Inglis, President of the Institution of Civil Engineers, and General Manager and Consulting Engineer of the Great Western Railway; the resident engineer being Mr. G. Lambert Gibson, M.Inst. C.E.

ONE OF THE FISHGUARD-ROSSLARE LINERS LYING OFF THE QUAY.

AT THE BOTTOM OF A SHAFT, SHOWING THE STAIRCASES LEADING TO THE THAMES TUNNEL.
(*From the Rischgitz Collection.*)

THE THAMES TUNNEL.

The driving of this famous Tunnel under the Thames by Brunel the elder may safely be described as one of the Greatest Engineering Feats of Modern Times.

THERE are thirteen tunnels under the Thames, and this total will be increased in the near future. We have already described the largest and most recent of these tunnels—the monstrous tube which burrows under the river-bed from Rotherhithe to Shadwell. In this chapter we shall take hold of the other end of the story of Thames tunnelling, as an account of *the* Thames Tunnel—Marc Isambard Brunel's tunnel, built in the early part of last century—can no more be denied a place among the world's engineering wonders than could King Charles's head be excluded from the thoughts of poor Mr. Dick. This not merely because the tunnel was the first driven under the Thames, or because a tunnelling shield was first used for its construction—facts which, taken on their own merits, would entitle it to a place. So many years have passed since the opening of the tunnel that this generation is largely unaware of the enormous difficulties which attended the work, and of the indomitable courage and resource shown by Brunel and his subordinates in combating them. The submarine tunnel-maker of to-day has at his service the Greathead shield and rotary digger, the supporting force of compressed air, applica-

The Thames Tunnel an Extraordinary Engineering Feat.

MARC ISAMBARD BRUNEL.
(From the Painting by Northcote in the National Portrait Gallery. Photo, Rischgitz Collection.)

tions of electricity for lighting and power purposes, highly-developed hydraulic and steam machinery, and a large number of precedents. His work is at times arduous enough —witness the Blackwall Tunnel and the New York subaqueous bores—yet he will readily admit that Brunel's feat, accomplished when iron linings and pneumatic shields and the electric lamp were not yet invented, and the steam-engine still in its infancy, stands unsurpassed in the annals of tunnelling.

Marc Isambard Brunel.

Marc Isambard Brunel was a Frenchman by birth, became a citizen of the United States by choice, and died an English knight. The greater part of his life was spent in England, where he busied himself in many useful inventions and a number of engineering works, of which the Thames Tunnel was the last and greatest.

Early Schemes for Tunnelling the Thames.

The need of easy communication between the two banks of the Thames east of London Bridge had become pressing at the end of the eighteenth century. As the construction of a bridge was out of the question on account of river traffic, engineers of that time gave their serious attention to tunnelling schemes. In 1798 a Mr. Dodd proposed a 900-yard tunnel between Tilbury and Gravesend. In 1802 followed a scheme to join Limehouse and Rotherhithe. A Mr. Vazie sunk a shaft to a depth of 76 feet below high water, and, aided by John Trevethick, drove a small heading under the Thames for a distance of 1,100 feet. Then the bed of the river gave way, water came in, the money available for the enterprise gave out, and the project had to be abandoned. A vast number of suggestions for carrying the matter through were made; but the fifty-nine selected for consideration by eminent authorities wilted under the verdict that an underground tunnel which would be "useful to the public and beneficial to the adventurers" was impracticable.

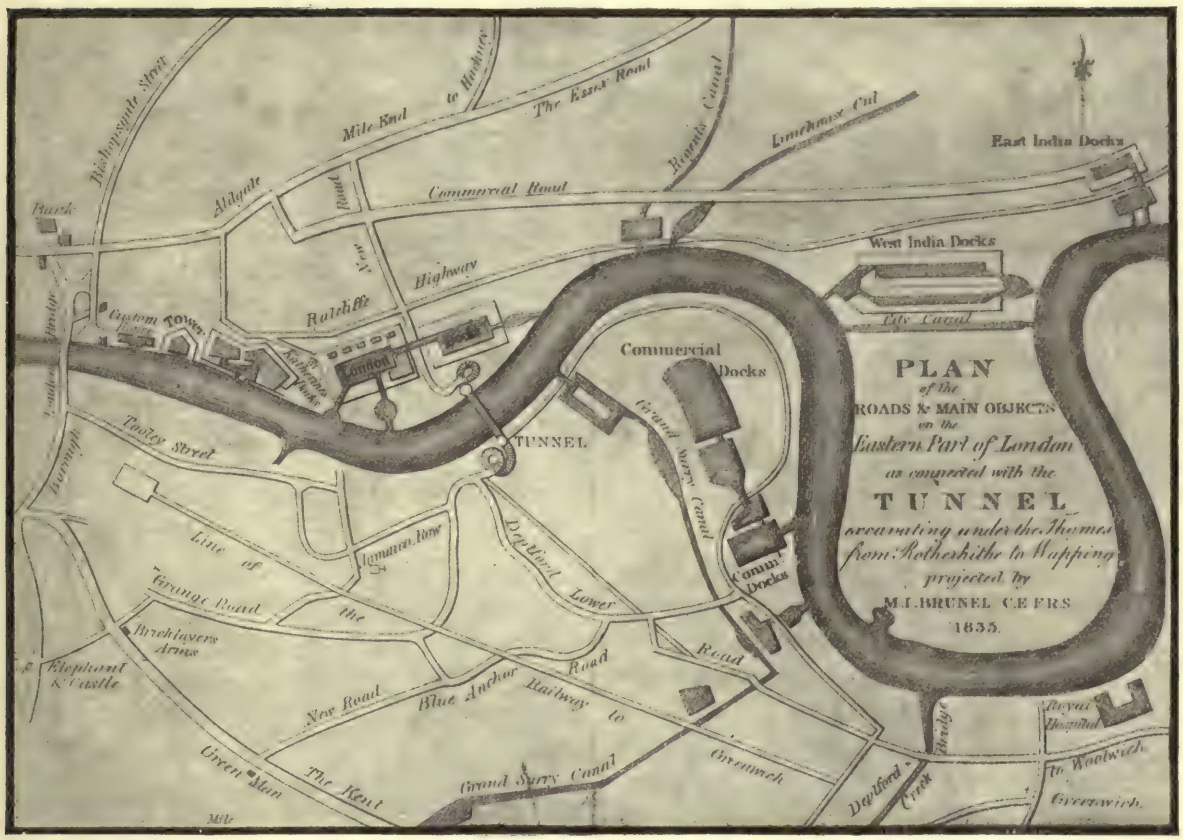
Brunel's Proposal.

When fifteen years had passed away, Brunel came forward with a proposal for driving a tunnel with the help of a shield, which should hold up the ground in front during excavation and allow brickwork to be put in behind. The tunnel was to have a rectangular section, 38 feet wide and 22½ feet high over all, and contain two parallel roadways separated by a wall pierced with arch openings.

The dimensions alone denoted a bold scheme —so bold that some critics declared it to be beyond the powers of a man who had had no experience in mining.

A Tunnel Company formed.

Brunel replied by explaining his shield method in detail. Scepticism gave way to enthusiasm, and at a meeting held on February 18, 1824, in the City of London Tavern, a company was formed, with a capital of £200,000, to



MAP OF EAST LONDON SHOWING SITE OF TUNNEL WORKS.

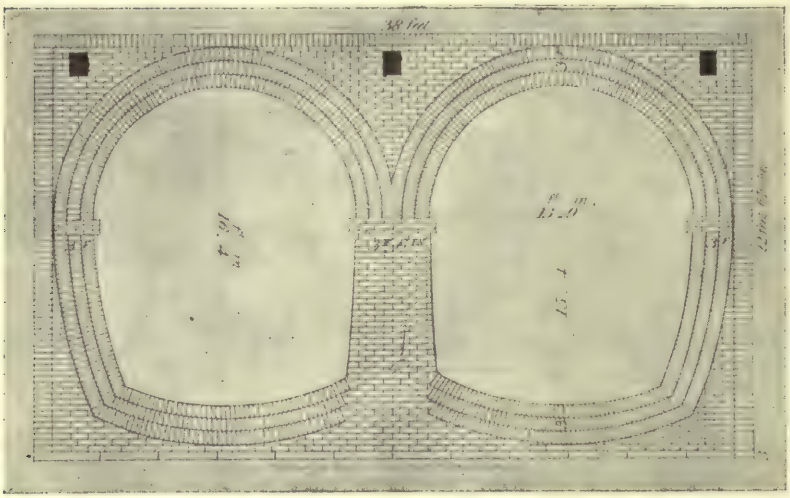
carry the matter through. The company immediately engaged engineers to make soundings along the line of the proposed tunnel. The report submitted by them set forth that under the river extended a stratum of blue clay sufficiently deep to ensure the safety of the tunnel.

Encouraged by this report, the directors appointed Mr. Brunel as company engineer, at a salary of £1,000 a year, and the promise of £5,000 when the tunnel should have penetrated fifty feet from the embankments; to which sum would be added a second £5,000 as soon as the first toll charge should be paid by the public.

On February 16, 1825, workmen began to clear a space on the Rotherhithe shore, fifty yards from the water's edge, for the erection of a brick caisson, 50 feet in diameter and rather more than 40 feet high. Short piles were driven into the ground to form a circle, and on them were laid wedges and a circular curb of iron supporting a wooden curb. This foundation was levelled with the greatest care, ready for the superstructure, the first brick of which was laid by the chairman of the company on the second day of March. Church bells rang merrily; a couple of hundred people feasted; large crowds shouted success to the undertaking.

The Shaft Caisson.

A temporary wall of bricks without mortar was built to a height of seven feet to secure an even bearing for the caisson. Though a dead weight of some 190 tons was superimposed in this manner, the settlement of the curb did not exceed one-sixteenth of an inch at any point. The workmen then removed the loose

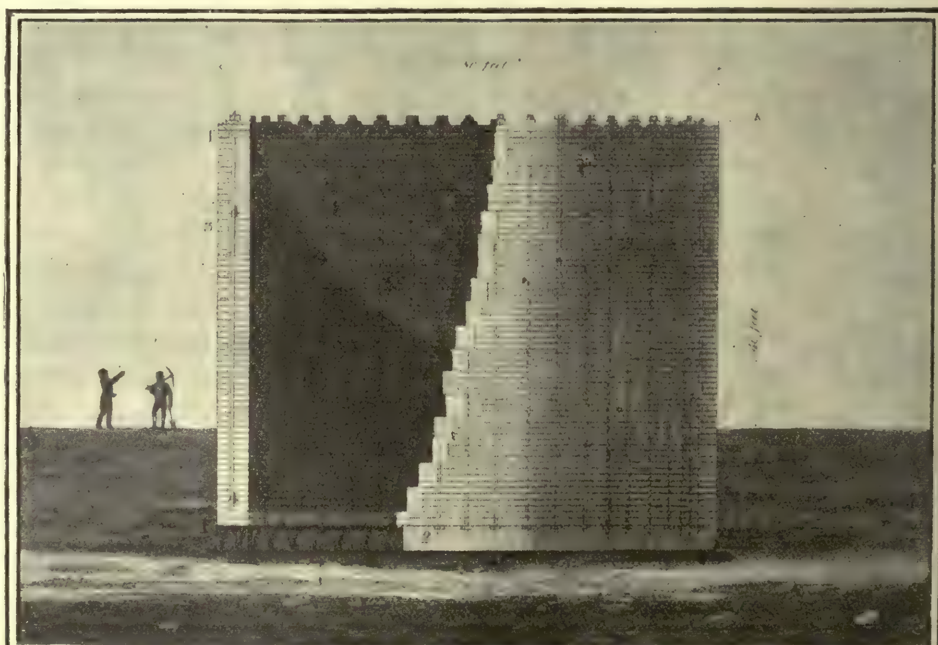


SECTION OF TUNNEL.

bricks, and commenced the permanent masonry, in which were built forty-eight 1-inch vertical iron bolts, extending from the lower wooden curb to another curb on the top of the caisson. The men worked rapidly, laying one thousand bricks each per day, so that the setting of the 900 tons of masonry was completed in three weeks, and the whole made snug by means of outside iron hoops and the vertical pull of the nutted vertical bolts. During erection the caisson penetrated the ground uniformly to the depth of half an inch.

The next operation was to strike out the wedges between the piles and the curb so as to bring these into contact, and to draw the piles and let the caisson rest on the gravel. This having been managed without difficulty, a staging was built over the caisson to carry the machinery for working an endless chain of buckets reaching down to the level of the lower curbs. Men stationed inside the caisson undermined its circumference carefully, throwing the spoil to the centre, whence it was raised by the buckets. The substitution of steam power for hand labour at the windlasses enabled the latter part of the excavating to be done at a better speed than prevailed during the earlier stages. By May 16 the iron curb had sunk to within a couple of feet of the required depth. Then

Sinking the Caisson.



BRICK CAISSON FOR SHAFT NO. 1.

Part of wall broken away to show tie-rods.

the friction between brickwork and ground held the caisson fast, nor could it be moved until 200 tons of bricks had been piled on the top. Early in June the curb reached its final position at the level of the crown of the future tunnel.

Under-pinning Work.

Brunel now proceeded to remove the curbs, a small part at a time, and continue the brick-work downwards for another 20 feet, leaving on the river-side an opening of the size of the tunnel, secured by stout timbering. A basin-shaped circular invert at the bottom completed the caisson. Great public interest was taken in this part of the work, and so many distinguished people visited the scene of operations that at times work was seriously hampered. Considering the difficulties of sinking even a firmly-bolted iron caisson, Brunel deserves the greatest credit for his skilful handling of a great masonry shaft which depended for its cohesion on the tenacity of mortar and the tension of a comparatively few metal rods.

Drainage.

Before tunnel-driving could be commenced, a large well had to be sunk under the invert for the pumps to deal with the water draining from the sub-river works. This operation proved troublesome, owing to the treacherous nature of the ground, and occupied a couple of months. It was Brunel's original intention to drive a small drainage heading from the well under the tunnel, so as to get the water away easily as well as test the ground in advance of the shield. But the directors baulked at what they considered to be an unnecessary extra expense, and requested their engineer to substitute—much against his will—a horizontal cast-iron pipe built into the masonry of the bottom of the tunnel. As often happens when those in authority interfere with the subordinate expert, the course laid down by them proved a costly mistake.

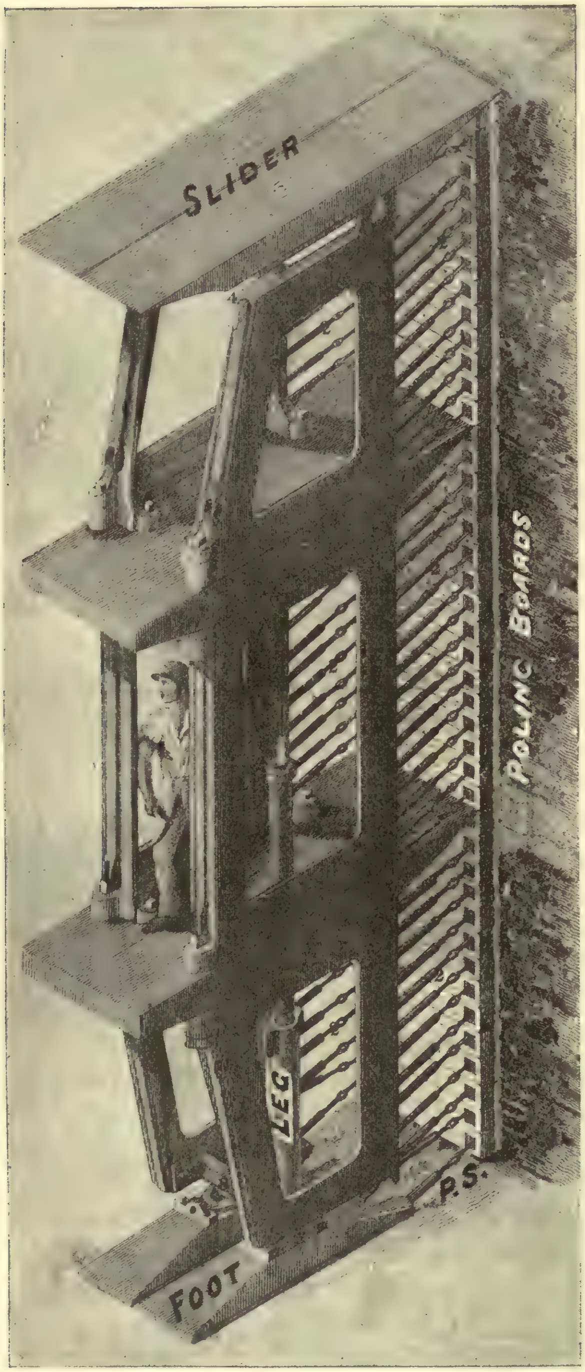
During the operations described above, the great shield had been constructed by William Maudslay, of the famous firm of Maudslay, Field, and Company. This ingenious device deserves a somewhat detailed description, as it may be regarded as the father of tunnelling shields, and was certainly the most important item of the plant used. But for it, the scheme would never have materialized.

The Great Shield.

The greatest difficulty in tunnelling through soft and treacherous strata is to support the ground attacked while giving the workmen access to it for excavation. The most vulnerable part is the roof. If timbering be used, considerable lengths of ground must be exposed while the timber is placed in position; and, where water lies in ambush, this process becomes extremely risky. Brunel therefore took a lesson from the *teredo navalis*, or ship's worm, which bores its way through wood by means of a pair of strong shell plates encircling its head. As this creature protected its mouth, so Brunel decided to hold up the ground immediately in front of the brickwork of the tunnel, as it advanced, by means of a shield covered in on both sides and provided with movable flat top and bottom.

Shield Details.

The illustration on the next page will help to explain the construction and principle of the device. It consisted of twelve vertical frames, each 3 feet wide and 21⅓ feet high, and divided by two platforms into three "cells." A frame stood upon two swinging legs, attached by ball joints to a couple of massive flat iron "shoes." At the top was the "head," carrying longitudinal iron sliders of sufficient length to cover the whole depth of the excavation, except for that part between a slider, when moved forward, and the brickwork behind. Experience caused "tails" to be added to overlap the brickwork, just as the corresponding part of a Greathead shield—to be described in a later chapter—overlaps the last ring of an iron tunnel lining.



ONE OF THE TWELVE FRAMES COMPOSING THE SHIELD.—P.S. = POLING SCREW.

The outside of the two flank frames had a vertical protective casing, and between every two frames were rollers to allow a frame to be moved forward without setting up excessive friction against its neighbours. To support the "working face" of the ground, a number of "poling boards," 3 feet long, 6 inches wide, and 3 inches thick, rose in front of the frame. Each of these had at the ends small iron plates countersunk at the centre to give a purchase to "poling screws," extending from the front rail of the frame to the boards.

Method of Excavation.

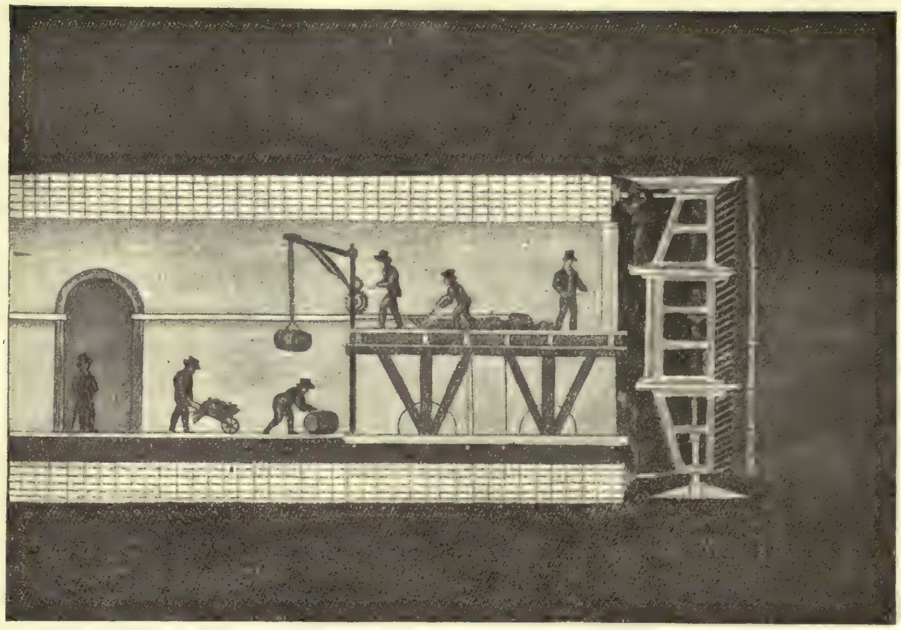
To make the operation of the shield quite intelligible, let us suppose the frames to be all in line and the thirty-six workmen about to attack the face after an advance of the shield. Each man releases the screws of the top poling board of his cell, removes the board, and excavates a strip of ground to the depth required. He then replaces the board, and forces it against the face by the screws. The other boards are removed and replaced in succession, working downwards, until the whole of his particular portion of the face has been treated.

Advancing the Shield.

When the time comes for an advance, alternative frames only can be moved simultaneously. It is impossible to force a frame through the ground with its boards and poling screws in their original position, so means have been provided for supporting the boards of a frame temporarily, independently of the frame. If frame 4, for example, has to be advanced, the miners release the screws in succession and insert their rear ends into a second set of notches in the adjacent front rails of frames 3 and 5, and screw them hard down. The simple diagram on page 187 shows the frames, poling screws, and boards as they would appear from above after the rear ends of the screws, *b b*, of frame 4 have been transferred to the notches in frames 3 and 5, and frame 4 has been moved forward.

The following method of advancing a frame was employed :—

First, one leg of the frame was screwed up so as to raise its foot clear of the ground. The



SECTIONAL VIEW OF TUNNEL AND SHIELD SHOWING TRAVELLING PLATFORM AND SCREWS FOR ADVANCING THE SHIELD.

foot was then levered forward into its new position and the leg screwed down tight. The other foot having been treated in the same manner, the staves of the head were forced forward into the ground. It then only remained to drive the body of the frame towards the poling boards by means of large screws abutting on the brickwork top and bottom (see cut on this page), release the poling screws from the neighbouring frames, and return them to the notches in their own frame. When all the "even" frames had been moved, the "odd" could be taken in hand. The extent of the advance was, in the earlier stages of the tunnel driving, only 4½ inches—half the length of a brick; but later on ampler movements were made, though not without proportionate risk.

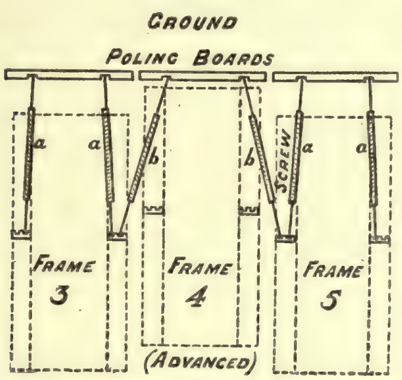


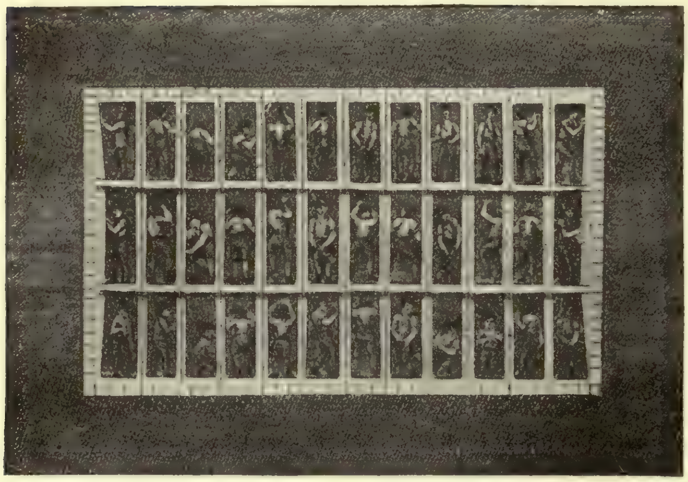
DIAGRAM TO EXPLAIN METHOD OF HOLDING THE POLING BOARDS DURING THE ADVANCE OF A FRAME.

The various parts of the shield were so constructed that any one of them could be removed without endangering adjacent parts, and this feature proved a most valuable asset on several occasions.

Tunnelling commences.

By the 28th of October, 1825, all twelve frames were in place, and a month later the shield began its historic journey under the Thames. The strata to be penetrated soon gave signs of being very different from the "good blue clay" of the preliminary report. Water found its way in repeatedly in sufficient quantities to delay the work, until the men had become more handy and had learned how to meet emergencies. The 80-ton mass of iron advanced at an average rate of about a foot a day for several weeks. On May 22, 1826, the top plate of frame 1 gave way unexpectedly, and by the end of the month the shield had got so much out of line that Brunel had to move it bodily eastwards three feet before going farther.

Some time earlier than this the chairman of the company had expressed the opinion that



MEN AT WORK IN THE THIRTY-SIX CELLS OF THE SHIELD.

with his tool held above his head. The increased movement of the frames strained them severely while they were being brought upright after the foot had been pushed forward, as the greater their inclination from the vertical the greater thrust did they exert against the head and foot when forced into a perpendicular position.

On September 8, 1826, diluted silt found its way through the shield in such quantities as to cause serious alarm. Its appearance was followed by an inrush of water, which fell into the tunnel in a regular cascade, and taxed the pumping plant to the utmost. Now was felt the need for a much larger drain than that specified by the directors, to carry away the water under instead of through the tunnel.

During the year the various parts of the shield had had to be renewed almost throughout. The replacement operations necessarily caused much delay. Yet, in spite of this and of the indisposition of one engineer after another, the work went steadily forward, and at the end of February 1827 visitors were allowed to visit the works, on payment of a shilling, and see for themselves what progress had been made. Their presence was not appreciated by the miners or engineers, as the ground became worse and worse, and the possibility of an irruption of the river more threatening.

When stones, brickbats, and other objects began to come down into the frames, Brunel thought it time to examine the bed of the river by means of a diving-bell.

River Bed inspected.

Inspection proved the existence of a hollow in the bed immediately over the shield. The workers at the face actually passed a pipe up into the bell and conversed with its occupants ! This fact gave little comfort to Brunel,

the shield was an unnecessary expense ; but those actually engaged below ground realized more plainly every day that, but for the protection afforded by the head and poling boards, they could not possibly have excluded the treacherous water-logged gravel and silt.

Isambard, Brunel's son, had from the first taken a prominent part in the conduct of operations, and had begun to show the genius subsequently proved by the Royal Albert Bridge, the *Great Eastern* steamship, the Box Tunnel, and many other great engineering works. His energy and resource contributed materially to the progress of the work.

Brunel the Younger.

The promoters of the tunnel, in their eagerness to hurry matters, presently decided to put the masons upon piecework. As a result the miners were continually being pressed, and, in order to enable them to keep ahead of the bricklayers, the amplitude of an "advance" of the shield was gradually increased, contrary to the desires of Brunel, who realized fully the risks entailed. The miner had eventually to excavate 18 inches ahead of his poling boards—a very difficult task in the case of the upper part of the face covered by his cell, which he must attack

A Mistaken Policy.

who shortly afterwards had to cope with a strike of the workmen lasting for several days —a period sufficiently long to allow the moving parts of the shield to become rusty and obstinate. Hardly had the men been persuaded to resume work when a great disaster occurred. On the evening of May 18 the river took control, invaded the shield, and drove the miners pell-mell to the shaft. All managed to gain the top except one old fellow, the engine attendant. Isambard Brunel, ever quick to act, seized a rope and slid down one of the iron ties of the shaft, followed by Mr. Gravatt, an assistant engineer. By means of the rope all three were brought safely up, and when the roll was called every man employed in the tunnel answered to his name.

First Irruption of the River.

CROSS-SECTION OF RIVER AND TUNNEL BED LOOKING NORTH.

The disaster came as a severe blow to Mr. Marc Brunel. But the news of it had hardly become public property before he was busy devising some means of rectifying matters. Bags were filled with clay, pierced with hazel rods, and flung into the deep depression over the shield. A large raft of timber was then placed on the clay with the aid of a diving-bell, the working of which was attended by several very narrow escapes from drowning. The raft proving unsatisfactory, it had to be removed—a very difficult business —and the clay-filling resumed until some 19,500 cubic feet had been thrown into the hole.

Remedial Measures.

This procedure stopped out the water, and rendered possible an inspection of the tunnel. The frames were found to be in their proper positions, unaffected by the terrific strain to which they had been subjected. Public enthusiasm ran high. Praise of Brunel's genius was in everybody's mouth. Two of the directors decided to explore the tunnel in a boat, which unfortunately capsized and caused the death of one of the workmen — a mishap that affected Mr. Brunel's noble heart much more than had the irruption of the river. In due course the large mass of mud blocking the tunnel at the shield end was removed, and the advance resumed. This happy event was celebrated by a banquet given in the tunnel itself by Isambard to a number of distinguished guests, and to a hundred of the leading workmen. But the general satisfaction was short lived. On January 12, 1828, the water invaded the tunnel a second time.

The Tunnel cleared.

A rush of air extinguished the gas lamps, and the workmen were left to struggle along in utter darkness towards the shaft, through water that was running like a mill race. Isambard had a foot jammed in some timber, and was held prisoner until the flood reached to his waist. He then managed to free himself

Second Irruption.

by a supreme effort and make his way to the staircase, already blocked by a panic-stricken crowd. Escape was cut off. Fortunately a tremendous wave which bore him to the top of the shaft enabled him to grasp the staircase, and so effect his escape. Six of the workmen, dragged by the wave back into the tunnel, were drowned.

While Isambard was recovering from the injuries sustained during this adventure, his father resumed the duties of resident engineer.

Funds exhausted. Tunnel bricked up.

Disregarding the hundreds of useless suggestions tendered for plugging the hole in the river-bed, he repeated his former plan and dumped down 4,500 tons of clay and gravel. This work exhausted the funds of the company. At a meeting called on July 5, 1828, the Duke of Wellington, who took a great interest in the tunnel, appealed to the public to subscribe for debentures which should enable the enterprise to be carried through. As the necessary help was not forthcoming, nothing remained but to brick up the shield and wait for happier times. The completion of this operation, early in August, terminates the first period of the tunnel's history.

Though through no inherent fault Brunel's method had failed to accomplish the desired end, the failure stimulated nearly five hundred

Many Suggestions.

would-be experts to submit schemes for completing the tunnel more cheaply and expeditiously than would be possible if his system were adhered to. Of these schemes all but one were rejected by the directors, and about this single exception the Duke of Wellington made some scathing remarks. The directors, nevertheless, looked so favourably upon it that Brunel felt it to be necessary to draw up a statement defending his own principles, and setting forth in detail the difficulties with which he had had to contend. A commission appointed to sit in judgment reported that the alternative plan was impracticable. This led to a resolution being passed by the shareholders expressing confidence in their engineer, and advising that an application should be made to Government for the funds necessary to carry on the work. Imagine the indignation of the shareholders when they learned subsequently that a loan had been offered by the Government, but refused by the management! Brunel's patience now gave out, and he resigned his appointment definitely in disgust.

Popular opinion would not, however, allow the tunnel scheme to fall through altogether. It was thought that Government should give the necessary aid. This en-

Government advances Money.

couraged the company to prepare a petition to Parliament; but, by some extraordinary fatality, when the time came for its presentation the petition could not be found! The Government consented, however, to advance £240,000 to the Tunnel Company, on condition that the money "should be solely applied in carrying on the tunnel itself, and that no advance should be applied to the defraying any other expense, until that part of the undertaking which is most hazardous shall be secured." This condition was unfortunate, as it prevented the sinking of the second shaft on the northern shore, and the simultaneous prosecution of the work from both ends.

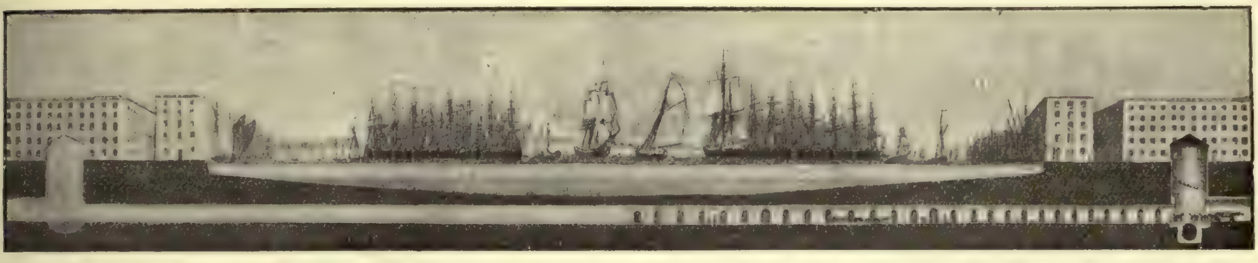
Brunel consented to associate himself again with the enterprise. His first task was to remove the brick heading-wall and replace the original shield—now in a ruin-

New Shield installed.

ous condition—by a new one embodying certain improvements. As a preliminary, the space occupied by the shield had to be timbered securely on all sides. This done, the frames and other parts were removed in detail. The new shield, built by Messrs. Rennie, was in place and ready for work at the beginning

of March 1836. To the credit of all concerned, the substitution had been made without the occurrence of any disaster more serious than a single case of pinched fingers.

The work to be done by the new shield caused occasional explosions in the shield, much to the dismay of the men. But the end was now in sight, and all concerned were determined that nothing should baulk them of the final victory.



LONGITUDINAL SECTION OF TUNNEL SHOWING PART FINISHED PREVIOUS TO THE TEMPORARY ABANDONMENT IN AUGUST 1828.

equalled almost exactly that already accomplished by the old, as the heading wall had been built midway between the sites of the two shafts. A very high tide tested the shield severely on June 21, and proved it to be splendidly designed and manufactured. Water caused continual trouble, and broke in three times in the course of twenty weeks, the last invasion occurring on March 1, 1838. The old plan of plugging the river-bed with clay was repeated, each time with success. At last the ground became so bad that Brunel forbade the removal of poling boards, and gave instructions that they should be forced forward through the silt. The miner had then to dig down behind each board in turn when the advance of that above it had opened a way for his tools.

Further Inroads by Water.

A novel and very unpleasant difficulty now presented itself in the form of sulphuretted hydrogen, smelling like rotten eggs. This poisonous gas caused so much illness among the men that the duration of a "shift" had to be greatly curtailed, and the means of ventilation greatly improved. To add to the general discomfort, an inflammable gas entered the workings, and

Trouble given by Poisonous Gas.

By April 1840 the shield had passed low-water mark on the north shore, and was within ninety feet of the site of the northern shaft, when an extraordinary subsidence of ground took place, leaving a pit in the foreshore 30 feet in diameter and 13 feet deep. The occurrence was not connected, however, with any trouble in the tunnel, though at the time it created great excitement among the spectators. Brunel had the cavity filled with clay bags, and then turned his attention to the building and the sinking of the second shaft. The latter operation required the greatest care, owing to the proximity of buildings, for damage to which the company was responsible. Taught by experience, Brunel gave this caisson a slightly conical form, to diminish friction, and sank it to full depth—70 feet—without underpinning.

A Curious Subsidence of Ground.

In August 1840, when the shield was but sixty feet from the shaft, a driftway was driven right through from the tunnel, and for the first time men passed under the Thames from bank to bank. In honour of the occasion Brunel was knighted by his sovereign.

Communication established under the River. Brunel knighted.

Sixteen more months passed, and then the shield came into contact with the brickwork of the caisson. This completed the work, except for joining tunnel to shaft—a somewhat difficult matter on account of the silt which forced its way into every crevice, and hindered the bricklayers greatly. In the very moment of his triumph Brunel was stricken with paralysis, which did not, however, prevent him from taking part, on March 25, 1843, in the ceremony of opening the tunnel.

The Tunnel opened.

The enthusiasm which marked this event contrasts strangely with the matter-of-fact way in which Londoners learned, sixty-five years later, of the opening of the Rotherhithe Tunnel. In twenty-seven hours fifty thousand persons made the sub-river journey—a striking proof of the general confidence in Brunel's structure; and in the course of the next four months the number of visitors rose to over one million.

Public Interest in the Work.

NOTE.—*The illustrations to this article (the first two excepted) are reproduced from an interesting booklet published by the Thames Tunnel Company in* 1837.

THE INTERIOR OF THE TUNNEL.

A BIG SPAN ON THE AFRICAN TRANSCONTINENTAL TELEGRAPH LINE.

THE AFRICAN TRANSCONTINENTAL TELEGRAPH.

BY HOWARD HENSMAN,

Author of

"*A HISTORY OF RHODESIA*," "*CECIL RHODES: A STUDY OF A CAREER*," *Etc.*

BRACKETING THE TELEGRAPH WIRE.

WHAT has come to be known as the trans-African telegraph line may in reality be described as the middle link of a chain of telegraph systems destined, within the course of a very short time, to bridge the entire African continent from Alexandria in the north to Cape Town in the south, throwing out numerous branches on either side in order to open up communication with the various settlements on the east and west coasts.

The Purpose of the A.T.T.

The scheme for the construction of this line originated with the late Mr. Cecil Rhodes, who saw in it, probably, a very useful pioneer for his other and more ambitious scheme for a "Cape to Cairo" railway. When the British South Africa Company first received its charter, and took over the control of that huge tract of country which is known to-day as Rhodesia, it was almost immediately decided to connect the larger towns—such as Bulawayo, Gwelo, Umtali, Salisbury, and Victoria—with each other by means of a telegraph wire, so as to provide a swift and easy means of communication. This was to be done chiefly in order to facilitate the instant concentration of the police and the white settlers at any given point where trouble threatened; for it must be remembered that, though the war against King Lobengula and his *impis* had quelled the warlike Matabele tribe for a time, it had by no means subdued it, as subsequent events were to show. In those early days, however, it was only proposed to carry the wire as far as Salis-

bury in Mashonaland—then as now the seat of the Rhodesian Government—with a possible extension eastwards through Portuguese territory to the port of Beira. Permission for the construction of this latter line was included in the Anglo-Portuguese Treaty dated June 11, 1891, but so far the work had not been taken in hand.

Riding alone one morning, towards the end of 1892, on the lower slopes of Table Mountain, Mr. Rhodes suddenly asked himself why the line should not be carried forward from Salisbury through Blantyre, the chief town of British Central Africa (so named after the little Scottish village where David Livingstone first saw the light), to Zomba, and thence, skirting the great lakes of Nyasa and Tanganyika, to Uganda and the Soudan, where it would eventually meet the Egyptian telegraph system which Sir Herbert Kitchener (as he then was) was busily pushing southwards as part of his scheme for the ultimate subjugation of the Khalifa and his followers. The more Mr. Rhodes thought over this idea, the more did it grip his imagination, if only for the fact that it would bring South Africa into so much closer touch with the Mother Country.

The A.T.T. Company incorporated.

After discussing the matter with several engineers, explorers, and others who had some acquaintance with the nature of the country through which the line would have to be carried, Mr. Rhodes finally determined that the idea was a practical one, and he outlined his scheme to his fellow-directors of the British South Africa Company. As a result, it was decided to form the African Transcontinental Telegraph Company, which was accordingly incorporated in December 1892. It was decided that the line should be built in sections, the first section being from Salisbury to Zomba, a distance of 430 miles, about 100 miles of which lay in Portuguese territory. The cost of this part of the line was estimated at, in round figures, £140,000, and the public were invited to subscribe for shares to this amount. Though some measure of interest was manifested in the scheme, the financial response was very poor, only £46,000 being subscribed by the outside public. Mr. Rhodes had therefore to find the balance—nearly £100,000 sterling—out of his own pocket. Work was then commenced, construction parties starting from both Salisbury and Zomba, and working towards a common meeting-place.

The Matabele Rebellion.

The line had barely got well started when the Matabele rebellion broke out, and delay at once began, since the material for the construction of the line was being brought up through Matabeleland by bullock-wagon, and it was, of course, impossible to get these supply trains through the disturbed area. However, just when arrangements had been completed hurriedly for bringing the poles and other equipment round by sea to Beira and thence to the route of the line by train and native carriers, the Mashonaland rising took place. Some 200 miles of wire had by that time been erected, the greater part through Mashonaland, despite the somewhat trying climatic conditions to which those engaged in the work were subjected, most of the route passing through dense, unhealthy forests, or over rocky ground so hard that the only means of providing holes in which to place the bases of the iron poles carrying the wire was to blast them out of the solid rock.

The Line destroyed.

About £40,000 were spent upon this portion of the route in labour, materials, transport, etc., and when the rebellion was at length stamped out and it was possible for the settlers to take stock of the damage that had been done, it was found that practically the whole length of the line had been destroyed, and that the wire itself had been looted and cut up to make slugs for the native riflemen. A lengthy pause then took

CREW OF AFRICAN TELEGRAPH COMPANY'S STEAMER "ADVENTURE," USED FOR CARRYING TELEGRAPH MATERIALS.

place while those responsible for the construction of the line decided what was the best thing to do under the circumstances. Mr. Rhodes went over much of the route in person. As a result of what he saw—and the engineers of the line were in complete agreement with him—he was convinced that a mistake had been made in choosing that particular route, and it was decided to start all over again and to write off as a bad debt the work that had been done.

This time the growing town of Umtali, some 170 miles south-east of Salisbury, was selected as the starting-point, and it was decided to carry the wire direct from here to Tete, on the banks of the Lower Zambesi, in Portuguese East Africa. Following this route, the wire passed over the high and healthy plateau of North-east Mashonaland, where the climate was much more genial and the country was not nearly so difficult to traverse.

Work was now pushed on energetically, with the result that, after many set-backs and disappointments, telegraphic communication was at last established between Tete and the south in April 1898. In the meantime, the line had been carried to Tete from Zomba, and thence forward to Abercorn, a small but growing settlement standing some ten miles from the southern shore of Lake Tanganyika, and close to the frontier that divides North-eastern Rhodesia from German East Africa. Another settlement on the lake itself, Kituta, was reached about a year later, after further delays, due mostly to the breakdown of the transport.

Work resumed.

A halt was then called in order that the next section of the line might be surveyed. The east shore of Lake Tanganyika, it should be explained, is in German East Africa, though the west is in the Congo Free State. It was decided, after full consideration, that the German shore afforded the best route, so Mr. Rhodes came to Europe and went to Berlin to see the German Emperor in person. It was his idea at that time to obtain from his Majesty the cession of a narrow strip of territory wide enough for the telegraph wire and the railway to pass through for the whole length of German East Africa, so that the "all red" nature of these schemes might be preserved. The Emperor, however, resolutely refused to consent to this, though, as Mr. Rhodes pointed out to him, the country was quite uncivilized, and would probably never be of the slightest value to Germany.

Negotiations with Germany.

In the end, however, Mr. Rhodes had to admit defeat and assent to the suggestion which was laid before him that his company and the German Government should work together in pushing this line through German East Africa; and an agreement to this effect was shortly afterwards entered into by the German Imperial Government and the African Transcontinental Telegraph Company. The German officials on the spot thereupon received instructions to render all possible assistance—instructions that have since been observed with the utmost loyalty.

Conditions imposed by Germany.

Labour troubles, however, quickly commenced to affect the progress of the line when work recommenced. The labourers for this part of the route were recruited from the native tribes of German East Africa, and were supplied by the German officials, but the demand was always very much in excess

AN INSPECTING PARTY PASSING THROUGH THE MAOONIE HILLS AT THE S.W. END OF LAKE NYASA.

of the supply. The climate, too, proved to be very trying for whites and blacks alike, and over considerable portions of the route no water for drinking purposes was obtainable. Owing to these and other drawbacks, such as the distance that the poles and other material had to be transported, it was nearly four years before the section of the line from Kituta to Ujiji (or, to give it its recently adopted official spelling, Udjidji) was reached. Udjidji is one of the most important settlements in German East Africa, and stands at about the middle of the eastern shore of the lake. This point was reached in May 1903. Udjidji is an uninteresting little town, composed mainly of low wooden huts roofed with ugly corrugated iron.

Labour and Climatic Conditions.

It claims, however, a niche in the history of Africa by reason of the fact that it was here that the late Sir H. M. Stanley met David Livingstone after his prolonged search in 1871. At this point construction work on the line has ceased for the time being, while the engineers in charge look around and decide upon the best route to follow for the comparatively short section of the line that is required to link it up with the Uganda and, subsequently, with the Soudanese system.

Route of the A.T.T.

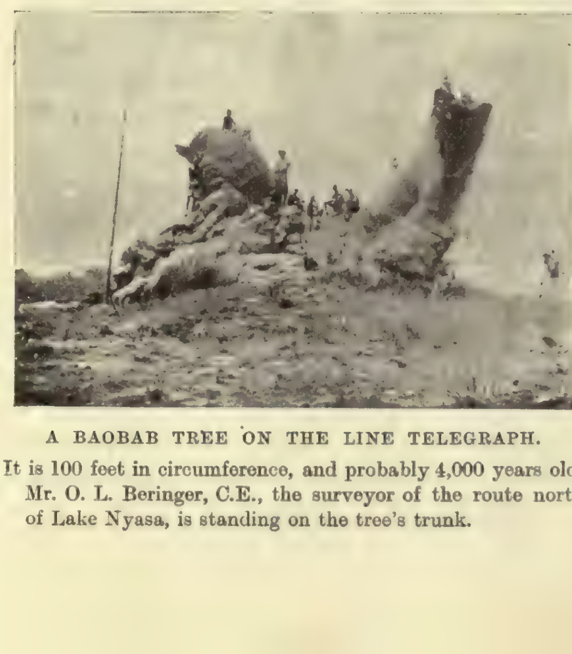
When construction is resumed, it is proposed to take the line in a north-easterly direction from Udjidji through the northern portion of German East Africa to Bukoba, a small town standing on the west coast of the great Victoria Nyanza, and thence

ON TREK WITH TELEGRAPH MATERIAL FOR LINE BETWEEN LAKES NYASA AND TANGANYIKA.

into Uganda, where it will be joined to the trunk line of that country, which crosses from east to west in close proximity to the Uganda railway. This junction effected, the transcontinental line will then be carried forward to the small settlement of Nimule, which is also in Uganda, and is only 90 miles from Gondokoro, on the southern edge of the Soudan, at which place the Egyptian telegraphic system has its termination. The distance from Udjidji to the Uganda line is about 420 miles, so that there is only a little over 500 miles more wire to set up before this great scheme of Mr. Cecil Rhodes will be completed and it becomes possible to send overland telegraphic messages from one end of the African continent to the other. The total length of the line from end to end will be, in round figures, 6,500 miles. This is, of course, far short of being the longest stretch of wire in the world; but when the nature of the country through which it has been carried is taken into consideration, and the many difficulties that have had to be confronted are recognized, it will be agreed that the trans-African telegraph wire is one of the most wonderful engineering feats of its kind that have yet been undertaken.

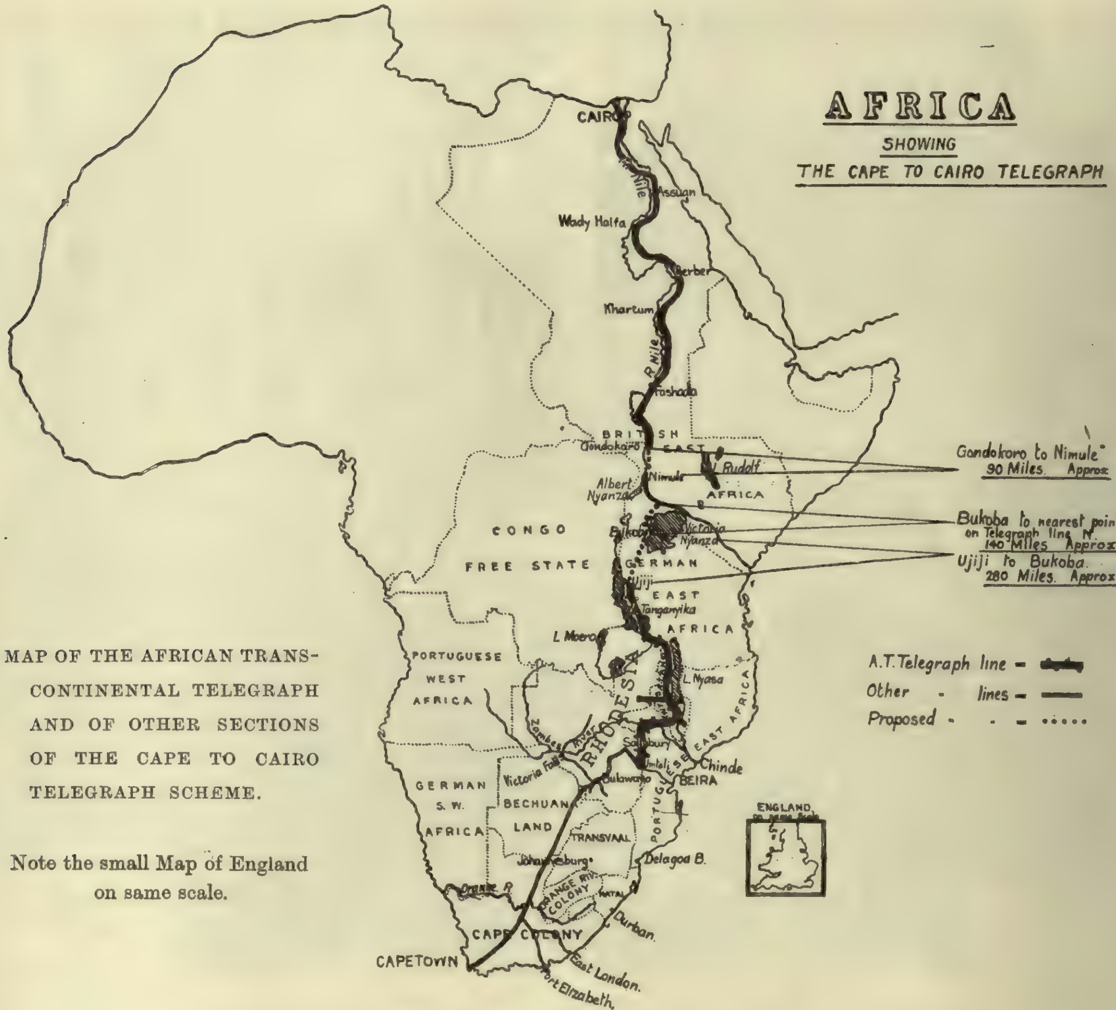
The actual length of the line belonging to the Transcontinental Telegraph Company is about 1,400 miles; and naturally in traversing this extent of country many physical changes have been encountered. Some of the country has been eminently suitable for the work, which has there been pushed forward with ease, while in other

SOME OF THE COUNTRY THROUGH WHICH THE AFRICAN TRANSCONTINENTAL TELEGRAPH PASSES, NEAR FIFE.



A BAOBAB TREE ON THE LINE TELEGRAPH.

It is 100 feet in circumference, and probably 4,000 years old. Mr. O. L. Beringer, C.E., the surveyor of the route north of Lake Nyasa, is standing on the tree's trunk.



MAP OF THE AFRICAN TRANSCONTINENTAL TELEGRAPH AND OF OTHER SECTIONS OF THE CAPE TO CAIRO TELEGRAPH SCHEME.

Note the small Map of England on same scale.

parts quite the reverse conditions have prevailed. In places, for instance, there have been miles upon miles of low-lying marshland that was unhealthy to a degree and caused much sickness among the construction staff; and in other parts dense jungles and forests, infested by wild animals and teeming with poisonous snakes, were found. Here and there, too, were mountain ranges, the previous existence of which had been almost unknown. These were intersected in places by deep ravines, in some instances from 200 to 300 feet deep and almost as wide across. These were at times quite impassable in the ordinary way for white men, and the expedient of lowering the workers down with ropes had to be resorted to. Very high altitudes were reached at times, especially at the commencement of the line as it passed over the North-east Mashonaland plateau, the wire being at times as much as 7,000 feet above the level of the sea.

Some Physical Obstacles.

Some wide and deep rivers were met with as the line was pushed forward, and the utmost ingenuity had to be displayed in getting the wire over them. The widest of them was the Zambesi, which is crossed in the neighbourhood of Tete. The river is here something like half a mile across. Considerable traffic passes up and down it, so

A Huge Span of Wire.

that specially tall poles had to be employed in order that the wire should not impede navigation at any state of the water. These poles are made of wrought iron, and are 60 feet in height. The river-banks at the point selected for the crossing of the line are respectively 34 and 38 feet high, so that the brackets on the poles to which the wire is attached are over 90 feet above the level of the water. The weight of the wire of this huge span, which is some 2,178 feet across, causes it to "sag" so much that in the centre it drops to within 54 feet of the river at low and 37 feet at high water level. The weight of this span of wire, it may be added, is 940 lbs. Poles similar to those employed on the Zambesi were employed for the passage of the Shiré River, though the span here is not so great.

A SIXTY-FOOT POLE BEING ERECTED ON THE BANK OF THE UPPER SHIRÉ RIVER.

The Telegraph Poles.

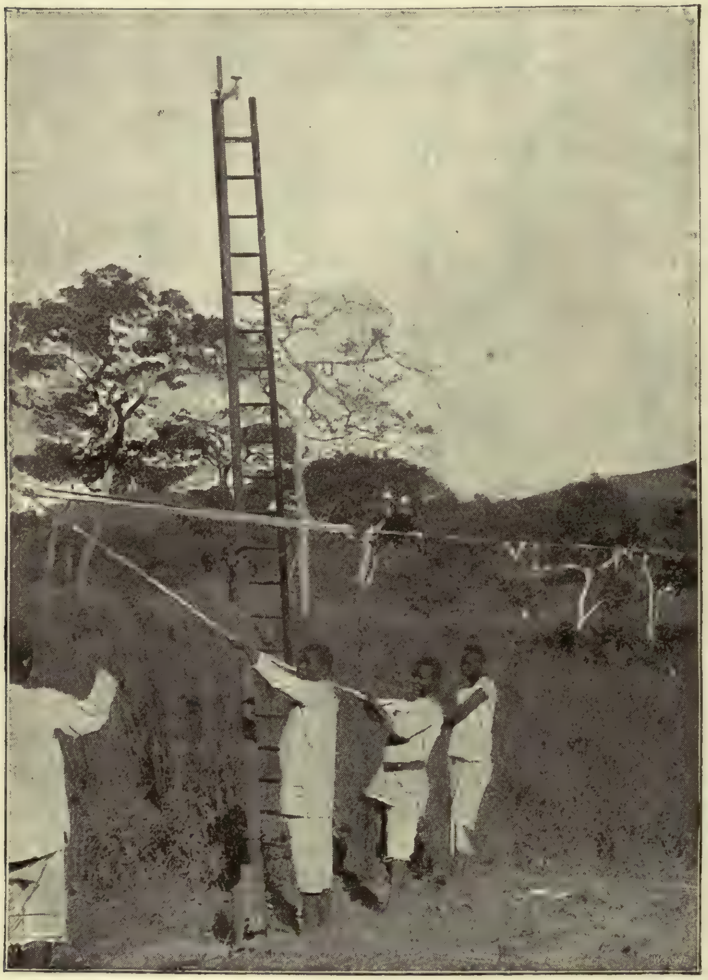
The poles usually employed along the line are graceful tapering ones of wrought iron, twenty feet high, with flanged bases, and, to facilitate transport, are made in two portions, easily fitted together at the site of erection. As a general rule they are placed about 100 yards apart, eighteen poles to every mile of country. For the most part the whole of the material for the construction of the line, as well as for the erection and equipment of the telegraphic stations, has had to be brought overland for long distances either by native carriers or by bullock-wagon, where the country was sufficiently open and level to permit of these methods of transport being used. The carriers displayed great powers of endurance. Their maximum load, 50 lbs. per man, they carried for days together without showing signs of fatigue. In certain parts of the line, however, it was possible to make use of the railway from Beira to Salisbury, and of the Zambesi and Shiré Rivers, on which the material and equipment were brought up in steamboats and dhows; but for the greater part of the line recourse had to be had to native carriers.

Attitude of the Natives.

The building of such a line through what was practically a virgin country must of necessity have had its exciting moments. Some of the tribes through whose country the line was carried were at times disposed to be very hostile, and it needed considerable tact, and at the same time firmness, on the part of the small construction parties to prevent a collision. Such tribes, however, were the exception rather than the rule. For the most part the innate curiosity of the natives overcame their fear or resentment at the white men's presence in their midst. At times they would cluster round in great eagerness to witness the work of erecting the poles and stretching the wire from one to the other. They had not the slightest idea what all the fuss was about, but were firmly convinced that there was "magic" in it somewhere.

Method of Preventing Injury to the Line.

Under no circumstances could these natives be induced to touch one of the poles or a piece of the wire, or to approach the spot where the testing-instruments were at work. The workmen's tools, however, attracted their cupidity—there is no greater thief in the world than the Central African native—and these they would purloin whenever they saw an opportunity. A very ingenious and uniformly successful expedient, however, was adopted for keeping them at a respectful distance. This was the sudden discharge of an electric spark from one of the instruments, which never failed to send



STRAINING THE WIRE.

all the spectators flying headlong into the bush squealing at the top of their voices, to the great amusement of the black "boys" attending the construction parties.

Actual encounters with wild animals were not so plentiful as might have been expected, but, of course, they occurred from time to time. Once a huge man-eating lion mounted guard outside the door of a testing-hut where one solitary operator was at work, and kept him a close prisoner for nearly a week. He had run out of ammunition, and had to telegraph to the next station, some considerable distance away, for a party to be sent to his rescue. Never once did the animal go more than twenty yards from the hut, and then only to drink from a pool near by. When it was eventually shot, it proved to be an exceedingly fine specimen.

Damage done by Wild Animals—

Herds of elephants were met with occasionally, but they caused no serious trouble. While waiting for material, however, or when there were delays from other causes, the constructors were wont to organize shooting parties, and some very fine "bags" were obtained. These elephants are, however, now proving a nuisance over the portions of the line where the wire has been erected. The poles in particular seem to have a peculiar fascination for them. They regard them as eminently suitable rubbing-posts—with disastrous results, since the pole has yet to be built that can withstand the caress of a full-grown African "tusker."

And by Vegetation.

Another expensive item in the maintenance of the line is the rapidity with which vegetation springs up in this part of the world. "Clearings," through the middle of which the line passes, were made in the jungles and forests. In the wet seasons of the year, however, climbing plants spring up with amazing rapidity, and entwine themselves around the posts and run along the wire, ultimately breaking it down with their weight; and during the heavy storms that take place in Central Africa at certain seasons of the year, huge trees are often blown against the poles or the wire, snapping both like so much matchwood and packthread. Another curious cause of trouble is the partiality that hornets show for building their nests between the

insulated brackets and the wire itself, thus causing the circuit to break and another "fault" to be reported. Owing to this state of things it is necessary to send out patrol parties constantly from every station to remove these obstructions and to repair the line. It is hoped in the course of time to overcome these present difficulties to some extent by making these clearings wider and more complete, so that when trees are blown down they shall fall clear of the wire, and the creepers may not be able to reach the poles before the patrol parties arrive and cut them back. The damage done by animals will, however, apparently always be present, and it seems impossible to devise any means of preventing this.

Health of the Constructors.

Taken as a whole, the health of the construction parties was surprisingly good throughout the whole length of the country that the line has traversed, and this notwithstanding the unhealthiness of the climate and the almost constant proximity of wild animals. Special precautions were taken, however, to protect those engaged in the construction work from the climate, and periodical medical examinations were held all along the line. The worst outbreak that took place was a severe epidemic of smallpox among one party working on the Tanganyika plateau. When one of the transport parties arrived at this plague-stricken camp, every man of the construction staff was found to be suffering more or less from the scourge. The native carriers, on realizing the true state of affairs, threw down their loads and fled in terror, nor could any amount of coaxing or threats induce them to return. Shortly afterwards an official of the Company who travelled up to the camp found the whole route for many miles strewn in all directions with material and equipment, lying where it had been thrown down by the frightened carriers. Though the greater part of this was subsequently recovered, the incident meant a substantial loss.

The line has demonstrated already its usefulness for other than purely commercial purposes. As soon as it reached the native settlement of Nkata Bay on Lake Nyasa, it was promptly made use of by the Joint Commission that had been appointed a short time previously by Great Britain and Germany for the delimitation of the respective spheres of influence of the two Powers in this part of Africa. By means of special relay apparatus set up at several stations, including Blantyre, Umtali, Salisbury, Bulawayo, and Kimberley, signals were exchanged between the Commissioners and the Astronomer Royal at Cape Town, which enabled the longitudinal and latitudinal points of the boundaries agreed upon to be determined far more accurately than would otherwise have been the case.

Commercial Success.

Even with the line in an uncompleted state the commercial returns have already been very good, and seem to indicate that it will be a great success when it is open from end to end. For the first ten years of its existence, ending December 31, 1907, 203,350 messages have been sent over the line or portions of it, containing in all 4,631,580 words, and the number of messages now being received and dispatched shows a steady increase month by month.

In addition to the main line from Umtali to Udjidji, there are two branch lines—one from Chikwawa to Chiromo at the mouth of the Shiré River, a distance of 67 miles; and the other from Domira Bay to Fort Jameson, the administrative headquarters of North-east Rhodesia and the headquarters of the African Transcontinental Telegraphic Company in South Africa. The length of this line (one of the best paying sections) is 128 miles. The united length of the main and branch lines amounts to 1,584 miles. Other branches will soon be built.

As a temporary expedient, and in order to make it possible to telegraph from the one

end of Africa to the other more quickly than might otherwise be possible, the suggestion has been brought forward that wireless telegraphic stations on the Marconi system should be set up at Udjidji, the present terminus of the wire, and at Gondokoro, the southernmost point of the Soudanese telegraphic system. The local authorities in German East Africa are strongly in favour of this, and an application is to be made to the trustees under the will of the late Mr. Alfred Beit, who left a handsome amount for the development of internal communications across Africa, for a grant to enable these stations to be built and equipped It is not proposed, however, that these should be regarded as permanent, and they would be used only until such time as the land line could be completed. The country north of Udjidji going towards Uganda is, however, of a nature that renders the erection of a telegraph line a work of considerable difficulty, inasmuch as it is for the most part low-lying marshland and swamps, interspersed here and there with dense jungles of close-growing tropical vegetation. Under these circumstances it is probable that considerable detours will have to be made when the country comes to be more accurately surveyed. It is felt, therefore, that a wireless telegraphy installation would be of great benefit, and would enable the Company to commence earning greatly increased amounts much sooner than would otherwise be possible. It is stated that the German authorities would be willing to bear part of the cost of building and equipping these stations, since the local authorities take a proportion of the revenue received from all messages passing over the portion of the line that lies within their territory.

Wireless Telegraphy.

NKATA REPAIRING STATION.

So far there has been no necessity to organize a police force to guard any portions of the wire from damage by marauding natives, as was found necessary during the construction of the Uganda railway, when Sikhs from the Punjaub had to be recruited to put a stop to the ravages of the natives, who ripped up the railway track bodily and conveyed it to their villages. As has been explained, most of the natives of the country through which the greater part of the line passes have a wholesome fear of the wire and everything connected with it, and the patrol parties that are sent out from the various stations from time to time to repair "faults," and to examine the condition of the line generally, manage to keep the tribes from interfering with it.

Police Patrols.

There have been many instances during the construction of the line of men, both white and black, continuing their work under circumstances when they had every justification for abandoning it, and there are on record instances in which have been performed deeds of a decidedly heroic character. Perhaps the most striking of these cases occurred when the first section of the line was being built from Salisbury to Tete, on

"EMINENTLY SUITABLE RUBBING-POSTS" (*see p. 200.*)

the outbreak of the rebellion in Mashonaland in 1896.

On June 16 of that year a telegram was received from Salisbury at the mining settlement of Mazoe, which the line had just reached, announcing that all the white men at the Beatrice Mine, some 40 miles from Salisbury, had been murdered by the rebels. All the white settlers around Mazoe were accordingly collected at the Alice Mine, and it was decided that an attempt should be made to reach Salisbury before a general rising among the blacks in the vicinity should occur. Telegrams were consequently exchanged with Salisbury, from which place a wagonette was promptly dispatched under the charge of a Mr. Blakiston, an employee of the Telegraph Company at Salisbury, to take back the women. Before it could get far on its return journey it was pursued and quickly caught up by a strong body of armed blacks. The whites had only five rifles and a very small supply of ammunition among them.

A Stirring Incident.

It therefore became necessary to telegraph to Salisbury for assistance. The telegraph office was, however, about a mile and a half from the spot where the vehicle was being held up; to reach it was a work of extreme danger. Messrs. Blakiston and Routledge—the latter being the local telegraphist—volunteered to attempt the task. They succeeded in fighting their way through the rebels, and ultimately reached the telegraph office and dispatched the message. Unfortunately, however, both were killed almost immediately afterwards as they endeavoured to force their way back to their party. Their gallant self-sacrifice was not in vain, however, for a strong party of horsemen speedily turned out from Salisbury and brought the party of settlers safely to the capital.

During the building of the line there have been several other instances of almost equal valour, and the construction staff generally has shown a spirit of unflinching courage and determination in the face of the utmost difficulties and dangers.

It may be added that, by special direction of Mr. Cecil Rhodes, and in order to preserve the "all British" character of the line as much as possible, the whole of the material necessary for the construction, equipment, and maintenance of the line has been purchased, and as far as possible manufactured, in this country. On the next page will be found a table of the principal distances on the line.

TELEGRAPH OFFICE AT KOTA KOTA, LAKE NYASA.

TABLE OF THE PRINCIPAL DISTANCES ON THE CAPE TO CAIRO TELEGRAPH LINE.

UMTALI TO BLANTYRE SECTION.

(*Total length,* 368 *miles.*)

Umtali to Inyanga	52 miles.
Inyanga to Tete	199 miles.
Tete to Chikwawa	90 miles.
Chikwawa to Blantyre	27 miles.

BLANTYRE TO KARONGA SECTION.

(*Total length,* 502 *miles.*)

Blantyre to Zomba	47 miles.
Zomba to Fort Jameson	77 miles.
Fort Jameson to Domira Bay	95 miles.
Domira Bay to Kota Kota	50 miles.
Kota Kota to Nkata	102 miles.
Nkata to Florence Bay	71 miles.
Florence Bay to Karonga	60 miles.

KARONGA TO BISMARCKBURG SECTION.

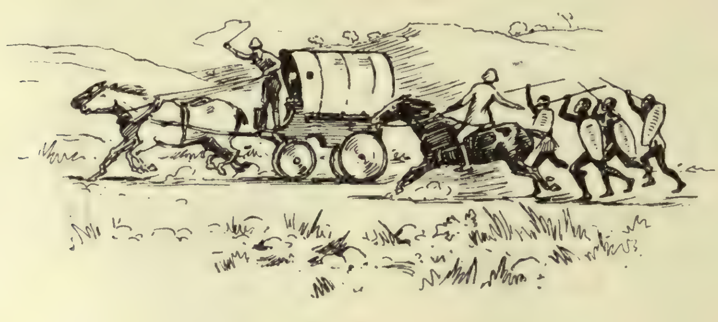
(*Total length,* 236 *miles.*)

Karonga to Fife	94 miles.
Fife to Abercorn	105 miles.
Abercorn to Bismarckburg	37 miles.

BISMARCKBURG TO UDJIDJI SECTION.

(*Total length,* 283 *miles.*)

Total length of main line	1,389 miles.



NOTE.—*This article is chiefly illustrated by Photographs kindly lent by the African Transcontinental Telegraph Company.*

THE GREAT VICTORIA BRIDGE

This Bridge, designed by Messrs. Robert Stephenson and A. M. Ross, was considered the "Eighth Wonder of the World" after its opening in 1860. It is one of the longest bridges in existence, and is notable also for the great difficulties that had to be overcome during its construction across the river St. Lawrence.

IN the middle of last century the physical obstacle to communications imposed by the river St. Lawrence had attracted to itself the very serious attention of the leading statesmen of the Canadian Provinces. For a distance of 900 miles—from the Niagara Falls to the Atlantic Ocean—the river was unbridged, and so set a northern limit to the rapidly extending Grand Trunk Railway system. During six months in the year navigation of the river is stopped by ice, which may be crossed on foot as soon as the ice-bridge has formed. But at the seasons when this natural bridge is forming and breaking up, the passage of the river is attended by the utmost danger, and there are instances of people dying from sheer fright while essaying it on sleigh or in canoe.

The Barrier of the St. Lawrence.

That the larger part of Canada should be thus cut off from the eastern provinces and the United States became intolerable. Ottawa, Montreal, and Quebec demanded that something should be done to provide a pathway for the locomotive. In 1852 the Canadian authorities requested the great firm of railway contractors, Sir S. Morton Peto, Brassey, and Betts, to examine the country and report upon the practicability of bridging the river.

A Bridge required.

Mr. A. M. Ross, C.E., was dispatched by them from England to Canada. He chose for the site of the bridge a point just above the

Note.—*The photograph at top of page shows the* NEW *Victoria Jubilee Bridge which now replaces the old tubular bridge described in this article. It was erected in 1897–8 without interfering with the traffic.* (*Photo, Exclusive News Agency.*)

city of Montreal, where the stream is about 1¾ miles broad, and, excepting in somewhat contracted channels, navigable only by vessels of very shallow draught. The bed is here of solid rock covered with clay, quicksand, and large boulders, some weighing many tons.

On his return to England Mr. Ross drew out designs for a tubular bridge very similar in its main details to the Britannia Bridge, then recently erected across the Menai Straits by Robert Stephenson, who was now asked to undertake, jointly with Mr. Ross, the final designs for the new structure.

Mr. Stephenson visits Canada.

He accordingly visited Canada in 1853, examined the site selected, and approved it. The bridge for which he was partly responsible had twenty-four tubular spans of 242 feet, and one of 330 feet over the central channel. To give sufficient headroom for navigation, the tubes rose from the ends to the centre of the bridge on an incline of 1 in 130, thereby increasing the distance between the bottom of the tubes and summer water-level from 36 feet at the abutments to 60 feet under the central span.

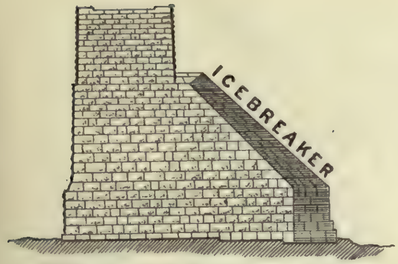
The construction of a bridge 1¾ miles long cannot be an easy matter under any conditions. In the case of the Montreal Bridge, the physical difficulties to be overcome were such as to include this structure among the most remarkable engineering feats of which there is record.

At high-water the St. Lawrence runs at a pace of from eight to nine miles an hour. To build piers amid so rapid a current promised some very difficult work, rendered all the more arduous in winter by the ice and in the summer by the huge rafts of logs, which, at the period of which we are speaking, were floated down the river to the Quebec sawmills.

THE OLD VICTORIA BRIDGE. *(Photo, Grand Trunk Railway Company.)*

As winter closes in, the early ice pens up the water, which rises behind it and impels it with terrific force down-stream. When a "shoving," as it is locally termed, occurs, the ice ploughs deeply into the banks, packs again, banks up the water, and continues its way until some obstacle or the tightening grip of winter cold brings it to rest—a chaos of hummocks piled up, in places, to a height of from twenty to thirty feet. When spring arrives, the ice begins to break up, and more shovings take place.

Ice "Shovings."



ELEVATION OF PIER.

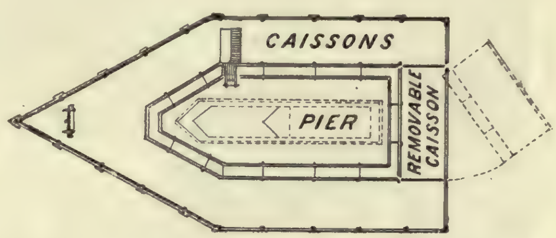
To withstand the enormous pressure of the ice, the bridge piers had to be of the most solid construction. It was decided to build them up from the solid rock with stones weighing from 5 to 20 tons apiece. The downstream face of a pier was vertical; the upstream face carried a large sloping ice-breaker, sharp edged, of stones bonded with iron clamps. This gave the pier an outline roughly resembling that of a boot, up which the ice would climb until its own weight shattered it on the sharp angle of the breaker. At summer water-level twenty-two of the piers measured 90 feet by 18 feet; the other two, those for the central span, 90 feet by 28 feet.

The employment of divers in an 8-mile current being impracticable, some plan had to be devised for excluding the water from the sites of the piers and abutments, and working on a dry bed. In a sluggish stream the formation of cofferdams would have presented little difficulty; here the reverse was the case. After careful deliberation, the engineers decided to build in the quieter water near the banks the caissons needed to form the walls of a dam, tow them into position, sink them, and line them with an inner wall of puddled clay, rammed hard down in a puddle chamber so as to exclude all water when the pumps should be set to empty the dam. To prevent the caissons shifting when once sunk, they were provided along the outside with steel piles, moving in grooves, which could be driven down into the bed of the river and so anchor the caisson.

Plan of Pier-building Operations.

During the winter of 1854, as soon as the ice-bridge had formed, the contractors began operations by marking out the positions of the piers on the ice, cutting holes, and taking soundings, while a road of a more or less level character was made, in the line of a bridge, over the rudely packed ice. The site for the centre of each pier was carefully marked by sinking an iron bar, 5 feet long and 4 inches in diameter, into the bed of the river, to serve as a guide for operations in the spring following. This done, large cribs of woodwork and stone were sunk in position above the piers to act as anchorages while the dams were being floated into position.

Marking out the Pier Sites.



PLAN OF PIER AND REMOVABLE COFFERDAM INSIDE WHICH IT WAS CONSTRUCTED.
The pointed end faces up-stream.

The spring of 1854 opened early. On the 24th of May the first caisson to form part of the dam for the north abutment was towed up-stream and sunk, and in due course that part of the river-bed on which the masonry was to rise had been pumped dry. The first stone was laid at the end of August 1854, and before work ceased for the winter more than 85,000 cubic feet of stone had been set. Meanwhile the approach embankment was built of stone faced with masonry on the up-stream side, and the dam for No. 1 pier—namely, that nearest the north abutment—was got into position and sunk. This pier was finished in November. Great trouble was experienced during the making of the dam for No. 2 pier, consequently for some of the other piers large cribs were used instead of caissons as barriers against the water.

Work commences.

BUILDING A PIER INSIDE A COFFERDAM.

The difficulties experienced by the contractors during this season were not physical only. Among so large a number of workmen, uninured to the climate, sickness soon appeared. In the winter they had been severely tried by the intense Canadian cold; in the summer they were decimated by cholera. We are told that out of a single gang of 200 men, 60 were on the sick-list simultaneously, and that of these many died.

Hygienic Difficulties.

Then there were labour troubles. The English workmen, unaccustomed to such hardships, became disheartened and struck frequently, utterly disorganizing operations for a time. During the ingathering of the harvest, when the great demand for hands caused farmers to offer very high wages, a large number of the men threw down their tools and made for the fields. One can realize the intense annoyance experienced by those in authority in the face of the fact that the period during which masonry could be laid was limited to sixteen weeks a year. It should be recorded, however, that all persons, such as the sub-contractors, who were individually responsible for a portion of the work, stuck to their tasks with the greatest possible zeal.

When the winter closed in, following an autumn of unusual heat, a great deal of damage was done to the cribwork by the ice-shove. The dams round No. 1 and No. 2 piers were carried away by the irresistible combined forces of over 124,000,000 tons of pack-ice, which groaned and ground its way along, presenting a scene too grand

Dams carried away by Ice.

VIEW OF BRIDGE PIERS DURING AN ICE-SHOVE.

for words. During the summer of 1855 the north abutment and piers Nos. 1 and 2 were finished, the dams for piers Nos. 3, 4, and 6 completed, and pier No. 5 built up 2 feet above summer water-level. A huge travelling crane had also been constructed by one of the sub-contractors on the south embankment for handling the large quantities of stone brought to the spot. This traveller, though of the crudest construction, being made by a man of resource who understood exactly what it would have to do, was found to be very superior to another machine which had been carefully built by an English firm and shipped to Canada. Mr. Hodges, engineer-in-charge, lays stress, *à propos* of this crane, on the resourcefulness which characterized men who, far away from conveniences of manufacture, were constantly called upon to solve mechanical problems.

Financial Troubles.

Operations were greatly delayed this year by a shortage of money resulting from the dislocation of business caused by the Crimean War, and at one time the temporary abandonment of operations was seriously considered. However, it was finally decided to go on with the works at all costs. The snow-storms of the following winter proved intensely severe, and the men had an extremely hard time of it. During the spring and the summer of 1856 the masonry was laid at a great speed—in fact, for a whole month the average rate for the works amounted to

13 cubic feet per working minute. In 1857 the piers were sufficiently advanced for the second part of the construction to be commenced—namely, the building of the huge iron tubes.

Preparations for Building the Tubes.

The reader may remember that in the case of the Britannia Bridge the largest central tubes were built on the shore, transferred to the bases of the piers on which they were to rest, and lifted to their final position by hydraulic presses. For the Victoria Bridge this plan was not feasible, and it was necessary to build every tube *in situ* on strong trusses of timber supported on piles. On the upper chords of the trusses were laid rails for the travelling cranes used in the erection of the iron work, which were brought up to the scene of operations upon trucks. The platforms that decked over the space between the lower chords of the trusses were about three feet below the underside of the tubes. On the platforms were laid three longitudinal lines of timber, carefully levelled to form a foundation for the ironwork.

An Example of Careful Manufacture.

It is not necessary to describe the process of assembling the tubes, but we may dwell for a moment upon the extreme accuracy with which the plates had been prepared in the works at Birkenhead. There every piece of iron before being shipped was given a number corresponding with one on the plans. Each tube contained nearly 5,000 pieces, but so orderly was the arrangement that when they arrived at the bridge site the workmen had no difficulty in sorting them out and building every part into its allotted place. A further proof of care is well exemplified in the components of the central tube, which numbered more than 10,000 and contained nearly 500,000 holes. Not a single piece required alteration, nor had a single hole been punched in the wrong place. It was well that the manufacturers had carried out their part of the work so faithfully, for the incorrect spacing of but a few rivet holes might have caused delays costing thousands of pounds.

The End in Sight.

During 1857 eleven tubes were erected, and it became evident that with good luck the next season would see the completion of the central piers, and also of two temporary piers between them to sustain a Howe truss extending across the opening to carry the central span during erection. It was of the utmost importance that all preparations should be finished before the winter of 1858 closed in; nothing more could be done when once the ice-shove should have commenced. The men, now on their mettle, worked nobly, and the temporary piers were placed before ice began to appear. Great anxiety was experienced as to whether these cribs would be able to withstand the shove. Under the test they proved equal to the strain, and as soon as the ice-bridge had formed, gangs of men transported huge quantities of materials to the stagings. The ironwork of the great central span had to be completed before the ice broke up in the spring; for, if the supports were moved at all with the span still incomplete, a disaster was inevitable.

Working against Time.

In spite of the intensely cold mists which rose from the water below and caused frost-bite, though the men all wore the heaviest clothing, work proceeded by night as well as by day. The tube grew quickly, and its increasing weight caused its temporary supports to give gradually under the strain. When the amount of deflection at last became serious, a large number of screw-jacks were inserted under the tube to lift it to the proper camber. About the middle of March 1859 a terrific storm destroyed some of the scaffolding erected at the side of the tube, and this was followed by heavy rains which rendered the ice very rotten

and dangerous. On the 25th the ice began to move; the riveting was not complete; a disaster seemed imminent! Many of the men, seized by sudden panic, commenced to run for the shore; others, blessed with cooler heads, thought it wiser to remain on the tube. A few minutes later the ice ceased to push, and the men, half ashamed of their fears, resumed their work. On the following day the last of the rivets were driven, and some of the wedges supporting the tube were knocked out; then, without any warning, the overburdened screw-jacks gave way simultaneously, and a tremendous shock was felt as the staging, suddenly released from its accustomed weight, sprang up a few inches. The first general impression was that the tube had been seriously damaged, but an examination revealed no signs of injury.

A Disaster threatened; and a Scare.

The work was completed only just in time. On the 28th the ice broke up and shoved very heavily, moving the temporary piers a couple of feet downstream. Had not each man toiled as though inspired with a belief that personal disgrace would attach to him if natural forces overtook the work, it is more than probable that the

Tube completed just in Time.

BUILDING A TUBE.

The overhead "traveller" was carried on the upper chord of a strong timber truss.

central span would have found a resting-place in the bed of the river. Thus ended a very exciting episode in the history of engineering.

Another cause of apprehension presently appeared in the form of huge rafts sweeping down-stream at such a pace as to be practically unsteerable. Large numbers of them, massed together, struck the dam surrounding the site of pier No. 11. Several men were upset into the seething waters among the logs and swept away; but, in spite of their apparently hopeless position, all the victims of this accident escaped with a good ducking. The crib, however, somewhat shaken by the collision, had to be repaired. Then things went ahead rapidly. To use the words of the engineer-in-charge: "The works presented a small island of crib-work surrounded by barges laden with stone, timber, steam engines, puddle clay, traveller stagings, and pumping machinery, in the midst of which were crowds of men apparently in the greatest confusion. This, added to the shoutings of the workmen, the noise of the pile engines, the 'yeo-heave-yeo' of the British boatmen unloading materials on one side, enlivened by a chorus of French Canadians chanting their boat-songs to the time of their work on the other, amidst a torrent of waters rushing past, with the surging and creaking of the barges as they tugged and tried to break adrift, formed, at first sight, such a bewildering scene of apparent disorder and confusion as can scarcely be described.

A Description of Working Operations.

"A careful survey, however, must have satisfied the observer that, instead of confusion, everything was order. Observing the gang of men driving piles with a steam engine at one place, he would not fail to notice that they were as indifferent to what was going on around them as if not a soul was there but themselves. So with a body of mechanics putting up pumping apparatus; or with the divers, the men working the air-pumps as unconcernedly and with as much confidence as a philosopher would prosecute experiments in a closet. At another place the dredging machine, worked by a steam engine, would be seen scooping every bit of loose material from the puddle chamber; while in the rear were men wheeling puddle into the cleared space, each side of which was lined with men armed with rammers, puddling and working the clay into every hole and corner so that there might be no leakage."

On August 2 the river-bed at the site of this, the last, pier was pumped dry, while outside the dam the river ran past at the rate of eight or nine miles an hour. The masonry was laid at such a pace that by September 26, 1859, the masonry of the bridge was completed. Before the end of the year the first train passed through the bridge. This event occurred simultaneously with a powerful ice-shove, which loosened the temporary staging that had carried the span and swept it bodily down-stream.

The chief operations remaining to be done were to roof over the tubes with wood and sheet iron, and to provide rails on which should run the travellers used in the painting of the tubes. From each end of the traveller hung platforms which could be swung outwards for the passage of a pier. The need for a proper provision of this kind will be understood when it is stated that the surface to be covered by each coating was no less than 32 acres—that is, the painters had to cover 128 acres, the area of a fair-sized farm, before the four coatings were on.

Painting the Tubes.

The stiffness of the bridge was tested by running over it trains averaging one ton per foot in weight. Under full load the deflection of the central span was found to be little more than one inch, and, in the case of the shorter tubes, only about three-quarters of an inch. In all cases the tubes returned to their

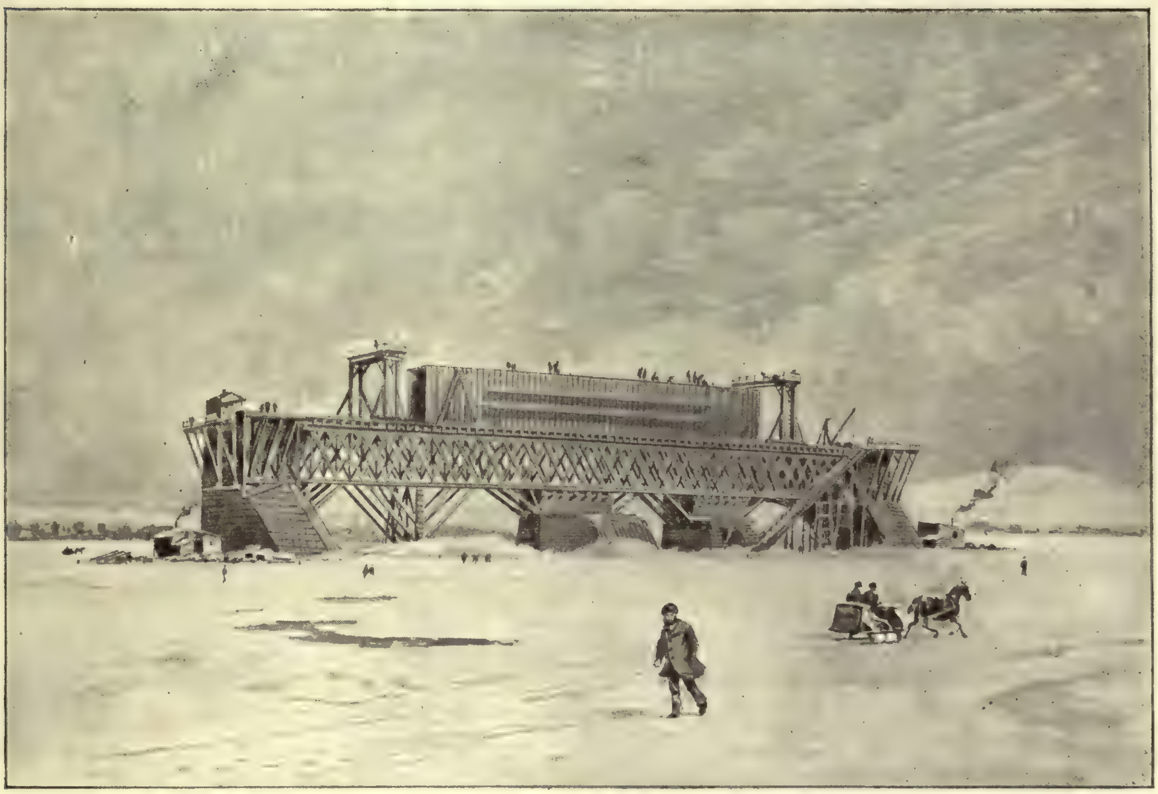
original positions as soon as the weight was removed. The engineers reported the tubes to be excessively strong as regards the load they were designed to carry, and attributed this to the thorough manner in which they had been fitted and riveted together, and to the excellent quality of the iron of which they were built. The bridge was opened by the then Prince of Wales on August 25, 1860, and named after his royal mother.

The Bridge opened.

The building of the Victoria Bridge was indeed a great feat. Engineers, contractors, gangers, and workmen alike were justifiably proud of their work. Climate, financial conditions, ice, disease—all had offered the greatest obstacles to the successful completion of the undertaking; and on purely sentimental grounds one cannot but regret that traffic conditions necessitated the substitution of trusses for the great Stephenson tubes a few years ago, when it was felt that a single track was not able to cope with the traffic for which passage was required.

The total length of the tubes was 6,592 feet, that of the bridge 9,144 feet. The weight of the tubes totalled 9,044 tons. The rivets used numbered over 1,500,000. Into the piers and abutments were built nearly 3,000,000 cubic feet of masonry. The temporary works consumed 2,280,000 cubic feet of timber, the staunching of the dams 146,000 cubic yards of clay puddle.

A graceful act marked the conclusion of operations. During the years 1846 and 1847 some 6,000 poor emigrants had died from cholera in temporary shanties erected near the site of the future bridge. The survivors, unable to bury the bodies separately, had



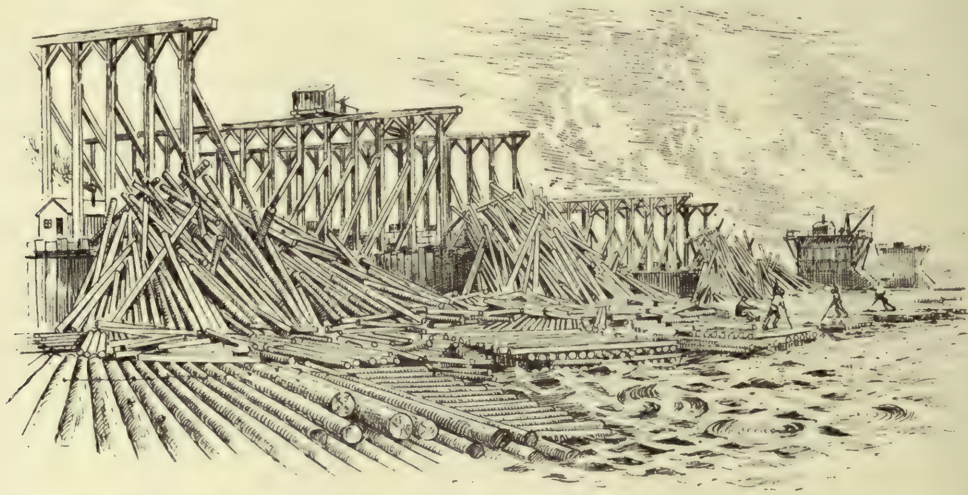
ERECTING THE GREAT CENTRAL TUBE OF 330 FEET SPAN.

The wooden truss carrying the tube during erection was supported by two temporary piers of crib-work.

interred them in a huge common grave, just as the plague victims of London had been buried nearly two centuries earlier. A small mound and a cross marked their last resting-place, which the workmen, rough as they were, were careful not to desecrate. Their active kindness of heart revealed itself in a desire to rear a more suitable monument. They moved a granite boulder, weighing some 30 tons, placed it on a pedestal, and cut on it an inscription setting forth that it had been erected by the workmen of Messrs. Peto, Brassey, and Betts engaged in the construction of the Victoria Bridge. The tubes that they built are gone; the monument remains.

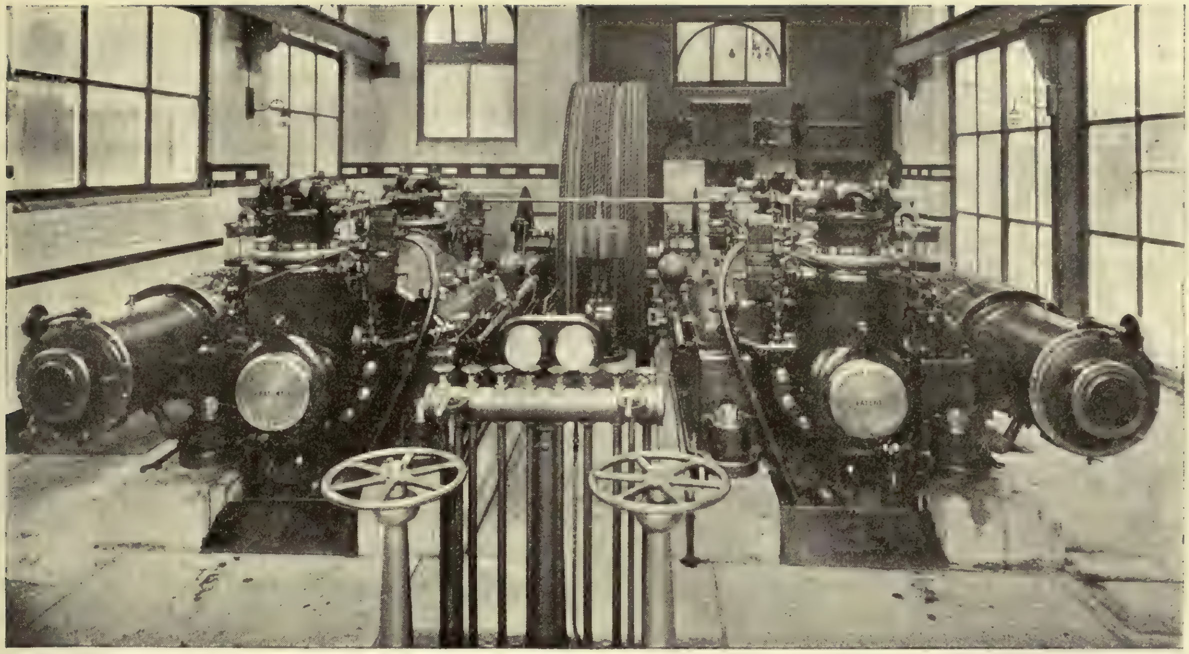
A Graceful Act of the Workmen.

The new bridge, named the Victoria Jubilee Bridge, was commenced in October 1897 and finished before the end of 1898. The original piers were lengthened to accommodate an open-work steel superstructure with double railway tracks, carriage ways, and footwalks for pedestrians. The replacement was made without interfering in any way with train traffic, the lattice girders being cleverly built round the old tubes, which were not removed until their successors were ready for use.



RAFTS COLLIDING WITH THE PIERS.

NOTE.—*The illustration on page* 206 *is reproduced from a photograph kindly supplied by the Grand Trunk Railway Company.*



(*Fig.* 1.)

THE DEVELOPMENT OF THE GAS ENGINE.

BY WILLIAM H. BOOTH, M.Am.Soc.C.E.

This Article describes how the once wasted Gases issuing from Blast Furnaces have been turned to very useful account as Fuel for Engines of Enormous Power.

IN the ordinary cylinder steam engine the energy of steam is made to do work by means of a piston which is driven backwards and forwards in the cylinder. The rectilinear motion of the piston is converted into rotary motion by a connecting rod and a crank. In the few cases where a steam engine is single-acting—that is, has steam admitted to one side only of the piston—the momentum of a fly-wheel mounted on the crank shaft serves to return the piston to the position occupied at the beginning of the power stroke.

The Steam Engine.

The work done by the steam engine is ultimately due to the heat produced in the boiler furnace by the chemical union of carbon fuel with oxygen of the atmosphere.

The Energy of Heat.

The heat communicates itself through the walls of the furnace to the water, which is vaporized in the form of highly elastic steam. We should note that very little of the furnace heat is finally converted into work—only

Note.—*The headpiece shows a 600 h.p. Körting gas engine, with two double-acting two-stroke cylinders, driving the machinery of a Lancashire cotton mill.*

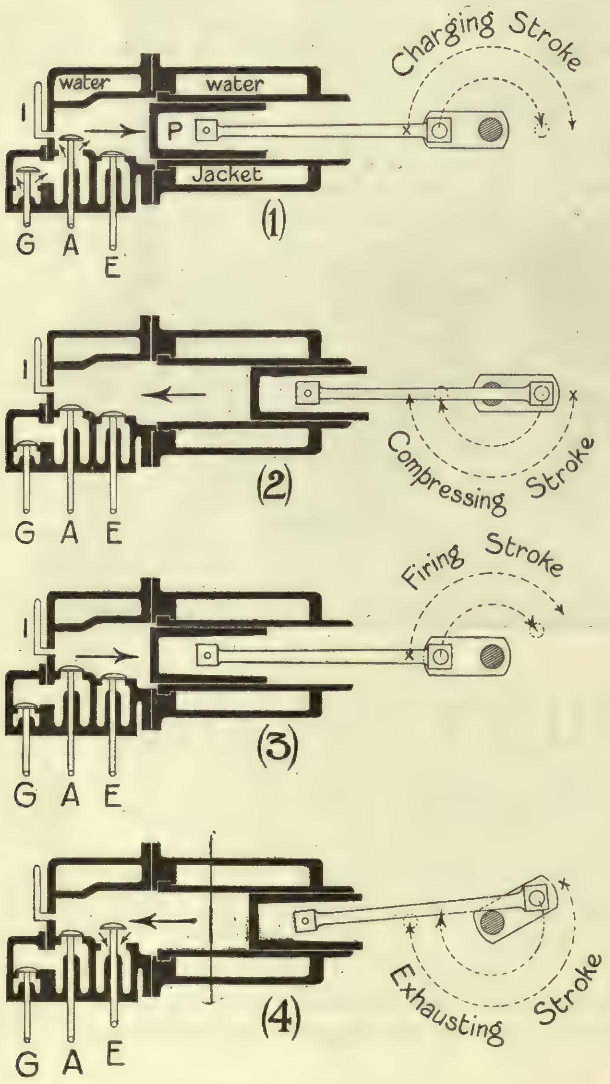


Fig. 2.—DIAGRAM TO SHOW THE FOUR STROKES THAT THE PISTON OF A GAS ENGINE MAKES DURING ONE "OTTO" CYCLE.

about ten per cent. in the best engines—the rest being wasted in the hot gases which escape up the chimney, passing off in the exhaust steam, and escaping through the metal of the pipes and cylinder. By careful "jacketing" the last loss may be minimized, while the principle of allowing the steam to expand in a series of cylinders of increasing bore also economizes heat. But in spite of all precaution and invention, the steam engine remains inefficient as regards the ratio of its output of energy to the fuel consumed.

The Internal Combustion Engine.

The gas or internal combustion engine has many features in common with the steam engine, the distinguishing difference being that the former makes the cylinder do the work of boiler and furnace in addition to that of extracting the power from an expanding gas. The chemical union of carbon and oxygen occurs *inside* the cylinder of a gas engine, and is so sudden that it has the nature of an explosion.

Early Gas Engines.

There is no clear evidence as to who first thought of using the explosive force of gas to drive a piston. The very early gas engines of thirty-five years ago were crude affairs. Their action was as follows:—The piston, dragged forward by the momentum of the fly-wheel, sucked gas and air into the cylinder. When it had travelled part of this stroke, the mixture was ignited by being momentarily exposed, by the opening of a port, to a flame outside the cylinder. The expansion of the burning charge produced pressure, and drove the piston to the end of its stroke. During the return stroke the burnt gases were expelled by the piston.

This method gave one power stroke for every revolution of the fly-wheel; but the action was irregular, and the results obtained were poor. Yet this type of engine proved a cheap motor where small power only was required, chiefly because it saved the wages that the user of a steam engine had to pay a stoker.

Beau de Rochas.

A critical period in the history of the gas engine was reached when a French engineer, M. Beau de Rochas, rediscovered the fact that, if gas and air be *compressed before ignition*, the pressure of the burning mixture is greater, and consequently the work done by a given quantity of gas is much increased. He made no practical use of his "find," but a German named Otto did. Hence it is that the Rochas "cycle," or series of happenings,

in a gas-engine cylinder is now known as the "Otto cycle." Fig. 2 explains the exact meaning of the "cycle," which is made up of charging (or suction), compressing, firing (ignition), and exhausting strokes, repeated *ad infinitum* in this order. You will gather from the diagram that only one push is given to the piston in the course of two revolutions of the crank.

The gas engine gets a good deal of work out of its fuel, as the fuel is actually enclosed in the cylinder. But so high is the temperature of combustion that the cylinder must be surrounded by a jacket, through which water circulates to absorb and carry off the excess heat. (In the case of air-cooled engines, air performs the same function as the water of the jacket.) Of course, the sacrifice of heat means a great waste of energy, but this is an unavoidable evil.

Cooling the Cylinder.

After the adoption of the Otto cycle, the gas engine grew in both popularity and size. The writer remembers being invited to see a *large* engine of 16 h.p., which, he was assured, represented the economical limit.

The second great advance in development dates from the time when Dugald Clerk covered in the cylinder in front, so as to permit explosions on *both* sides of the piston, and thereby gain double power with very little increase of weight. Another equally important novelty was the introduction of separate gas and air pumps for driving the charge into the working cylinder, which no longer had to act as a pump. The two improvements made it possible to get an impulse stroke *every* revolution of the crank—instead of one every two revolutions, as in the Otto cycle—in both directions, and so brought the gas motor almost into line with the double-acting steam engine as regards its steady turning action. Clerk did not reap any great advantage from his inventions, but

Dugald Clerk's Improvements.

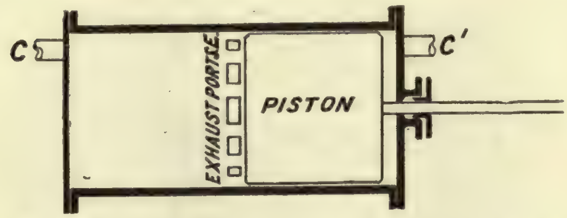


Fig. 3.—DIAGRAM OF CYLINDER AND PISTON OF A CLERK DOUBLE-ACTING ENGINE.

lived to see his ideas materialize in some of the best of the great gas engines of to-day. A sketch of a Clerk engine is given in Fig. 3. The fresh charges of air and gas entered the cylinder at C and C^1 alternately, driving out the burnt charge through exhaust ports, E, and were compressed by the piston on its return stroke and fired at the dead point.

Despite great improvements in design, progress in size remained slow, as public lighting gas was the only fuel available. Now, this gas is manufactured to give light primarily, and its illuminating qualities, though expensive to obtain, are of no use in a gas engine. For this reason the big engine did not come along until a cheap fuel had been provided by the introduction of the "poor gas"—poor in hydrogen—producer. Fig. 5 shows a producer in section. A is a chamber lined with fire-brick, and fed with fuel—anthracite coal or coke—through a bell-top similar to that of a blast furnace. Most of the chamber is filled with incandescent fuel. Air, either forced by a pump or sucked by the engine, enters under the fire-bars and passes up through the fuel.

The Gas "Producer."

Then chemical action commences. An atom of incandescent carbon takes to itself as partner two atoms of oxygen, to form a molecule of carbonic acid gas (CO_2), which is incombustible because the carbon has got all the oxygen it requires. But further travel through the fuel causes each molecule to adopt another atom

Chemical Action in the "Producer."

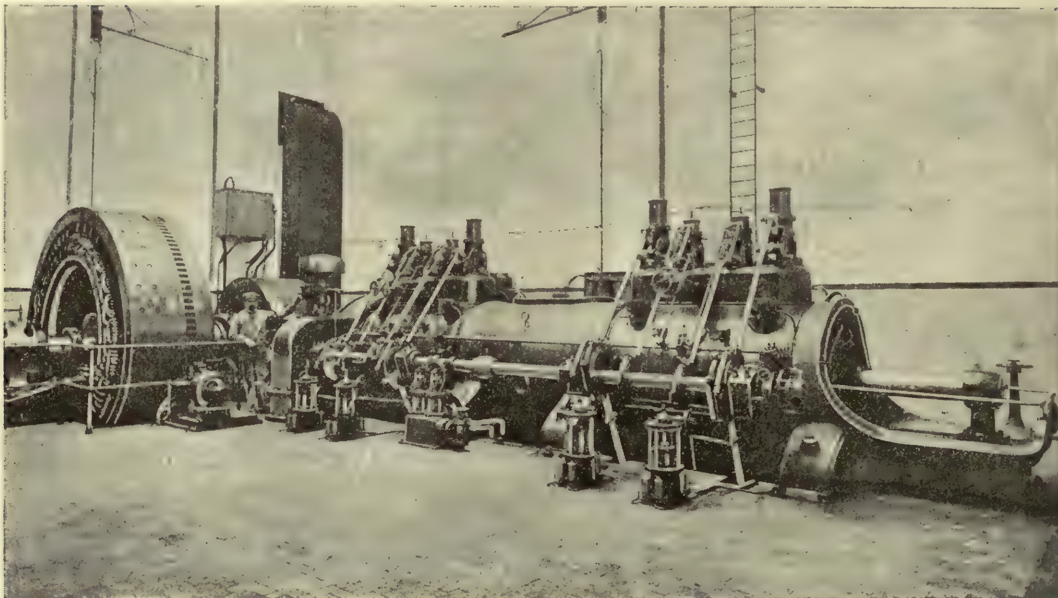


Fig. 4.—NÜRNBERG ENGINE OF 900 H.P. TWO CYLINDERS TANDEM.
Running on blast furnace and coke oven gas at Brymbo Steel and Iron Works.

of carbon, and break up into two molecules of carbon monoxide (CO), which *can* burn. (It causes the light-blue flames that play on the top of an ordinary open fire.)

The gas that reaches the top of the producer is of this kind. Before becoming usable it must be cleaned, and therefore is passed through a *scrubber*, B, filled with coke perpetually flooded by water issuing from a number of jets above. The water absorbs dust and other deleterious elements. The purified gas consists of about one part of carbon monoxide diluted with two parts of nitrogen. It may contain more or less hydrogen, if steam be mixed with the air and decomposed by the hot fuel. Such a gas has no illuminating power, and is much less explosive than lighting gas; but it is *cheap*, and serves its purpose excellently. The producer itself is essentially so simple that it cannot well be damaged by its attendant, who has merely to keep it full of fuel.

Cheap Gas.

The gas engine was now independent of a town supply. Wherever a producer could be erected, there an engine could be worked. This led to a regular boom in the manufacture of the machines, and, as often happens when business is profitable, to a certain stagnation in design and cessation of scientific experiment. A few men only strove after improvements, and encouraged fuel economy by means of competitions. The producer was all right in its way, but not suited for engines

Boom in Gas Engines.

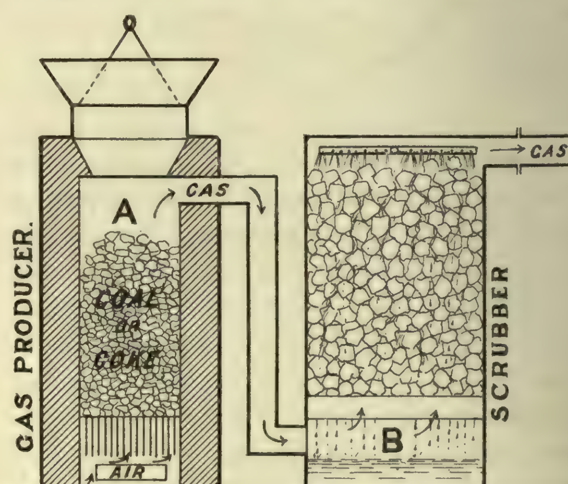


Fig. 5.—SECTION OF GAS PRODUCER AND SCRUBBER.

of very large power, as the gas it made was, though cheap, not cheap enough to be used in very large quantities. It remained for a brilliant but unfortunate inventor, Mr. Benjamin Howarth Thwaite, to realize that the gas issuing from the top of an iron-making blast furnace could be pressed into the service of the gas engine—that the blast furnace was, in fact, a huge producer. One day in 1894, while he was analyzing a sample of ordinary producer gas, he was struck by the close resemblance which it bore to blast-furnace gas. The latter had already been turned to account to heat the stoves of cellular brickwork through which blast air is driven on its way to the furnaces, and as fuel under the boilers supplying steam to the blowing engines. For the second purpose, however, it proved very inefficient, owing to the presence of dust and carbonic acid gas.

B. H. Thwaite's Discovery.

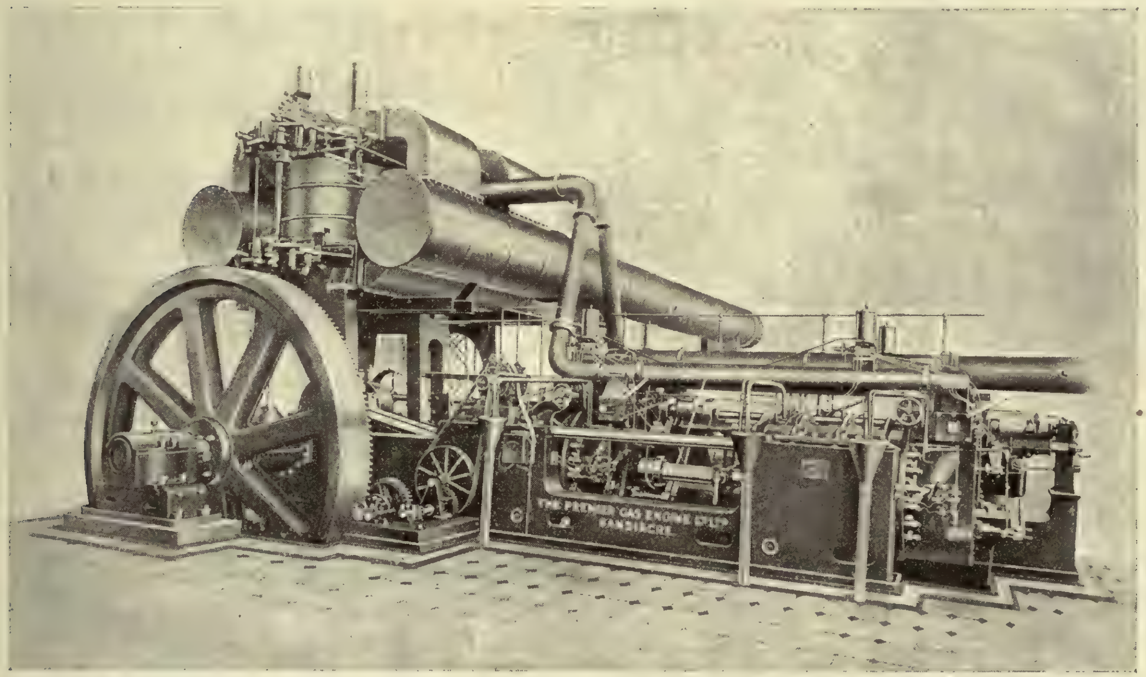


Fig. 6.—A FOUR-CYLINDER PREMIER GAS ENGINE OF 2,000 H.P. USING BLAST FURNACE GAS.

The huge vertical blowing tub delivers 40,000 cubic feet of air per minute at a pressure of 7 to 8 lbs. per square inch. This supply would give a ten-mile-per-hour current in an 8-foot diameter pipe; while the hot gases to which it contributes in the blast furnace would travel at the rate of twenty miles per hour through a pipe of equal size.

A Successful Test.

Thwaite purposely manufactured a compound of the same chemical nature, and set his engine to work on it. It was an anxious moment for him, as on the result depended the decision whether the millions of cubic yards of furnace gas going to waste could or could not be used effectively in an engine. Would this gas, scarcely combustible under a boiler, burn well in a cylinder when mixed with the necessary amount of air and compressed? Experiment proved that his reasoned expectations were justified—the gas burned and the engine ran well.

Shortly afterwards, Thwaite published an article in the *Iron and Coal Trades Review* describing the possibilities of the fuel. Sir Lowthian Bell, the great ironmaster, interested

himself in the discovery, but was struck down by a fatal illness before its importance had been proved. The inventor was enabled, however, by the help of Mr. James Riley of the Glasgow Iron Company, to put his idea into actual practice at the Wishaw Works, near Motherwell. The works were lighted successfully with electricity generated by an engine built to use blast furnace gas—the first engine of the kind. The second was established by a Belgian firm at Seraing, and its good behaviour led the Germans to interest themselves also.

Like many another inventor, Thwaite found himself a prophet without honour in his own country. The gas might burn well enough, folk said, but what about the dust with which it was so generously charged? Rich

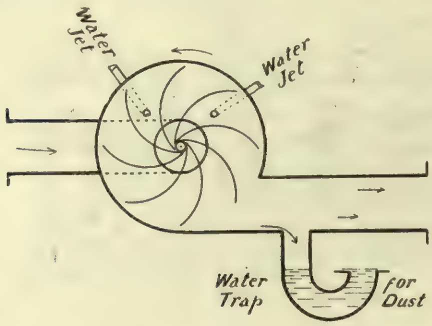


Fig. 7.—FAN-TYPE DUST EXTRACTOR.

men showed him their backs, but with commendable perseverance he continued to devise efficient "scrubbers" for ridding the gas of its noxious dust, the harmful qualities of which were only too apparent. The first scrubber used by Thwaite consisted of a wetted fan and a sawdust filter. The fan was one of the ordinary centrifugal type, into which the gas enters near the centre (Fig. 7). As it rotates, it whirls the gas violently round and flings it against the walls of the casing, whence it is washed, by water squirted from the side, into a trap, and so collected. A subsequent passage through a sawdust filter removes the last

Cleaning Blast Furnace Gas.

traces of dust. At Ettingshall Works there are three such fans arranged "tandem" (See Fig. 17), through which the gas travels suc-

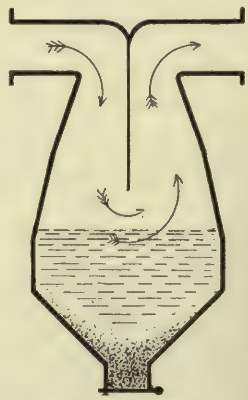


Fig. 8.—ANOTHER TYPE OF CLEANER.

cessively. The water flowing from the first is black, that from the third a dirty milky colour, which means that very little, if any, dust has escaped the water.

Other forms of scrubbers are shown in Figs. 8 and 9. Fig. 8 is perhaps the simplest type—a chamber with a vertical partition which suddenly changes the direction of the flow of the gas, and causes the heavier particles to be deposited at the bottom. Another kind of washer (Fig. 9) is used for lighter dust. It contains a number

Various Types of "Scrubbers."

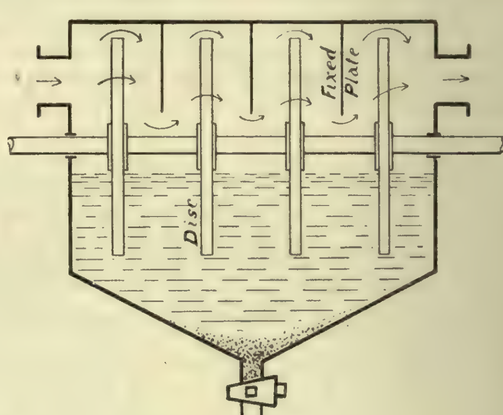


Fig. 9.—REVOLVING DISC TYPE OF SCRUBBER.

of metal discs attached to a horizontal shaft and enclosed in a cylindrical tank partly filled

with water. Plates projecting from the sides of the tank compel the gas to come into contact with the moving wet surfaces of the discs, which catch the dust and wash it off as they pass through the water below. The mud is

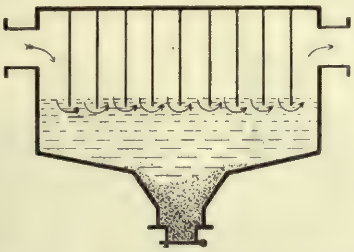


Fig. 10.—DIAPHRAGM-TYPE SCRUBBER.

drawn off through a cock at the bottom. A third type (Fig. 10) causes the dirty gas to pass repeatedly under the lower ends of diaphragm plates immersed in water.

These illustrations, to which should be added

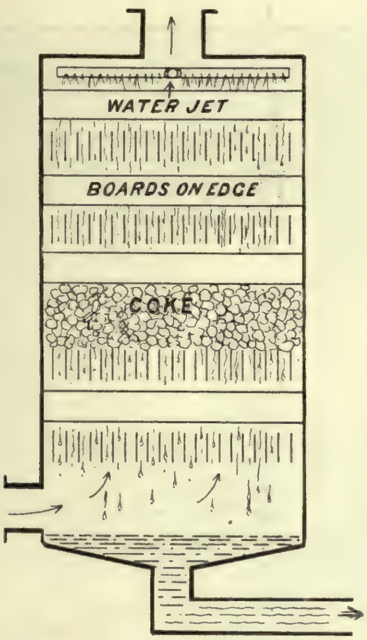


Fig. 11.—SCRUBBER FOR ORDINARY GAS PRODUCER.

Fig. 11, showing an ordinary gas-producer scrubber, will give the reader a fair idea of how this particular difficulty has been dealt with and overcome.

Though Thwaite did not make much headway in England, his experiments were much appreciated on the Continent and in America. At the Paris Exhibition of 1900 there was shown a huge blowing engine of 750 h.p., operated with blast-furnace gas. It had a cylinder of 4 feet 3¼ inches bore and 4 feet 7 inches stroke, ran at 80 revolutions per minute, and with an initial explosion pressure of from 310 to 325 lbs. to the square inch produced a piston thrust of 300 tons. It is now at work blowing furnaces at Ettingshall.

Still larger engines followed, some constructed on the Otto four-stroke cycle, and provided with a sufficient number of cylinders to give a regular turning effort.

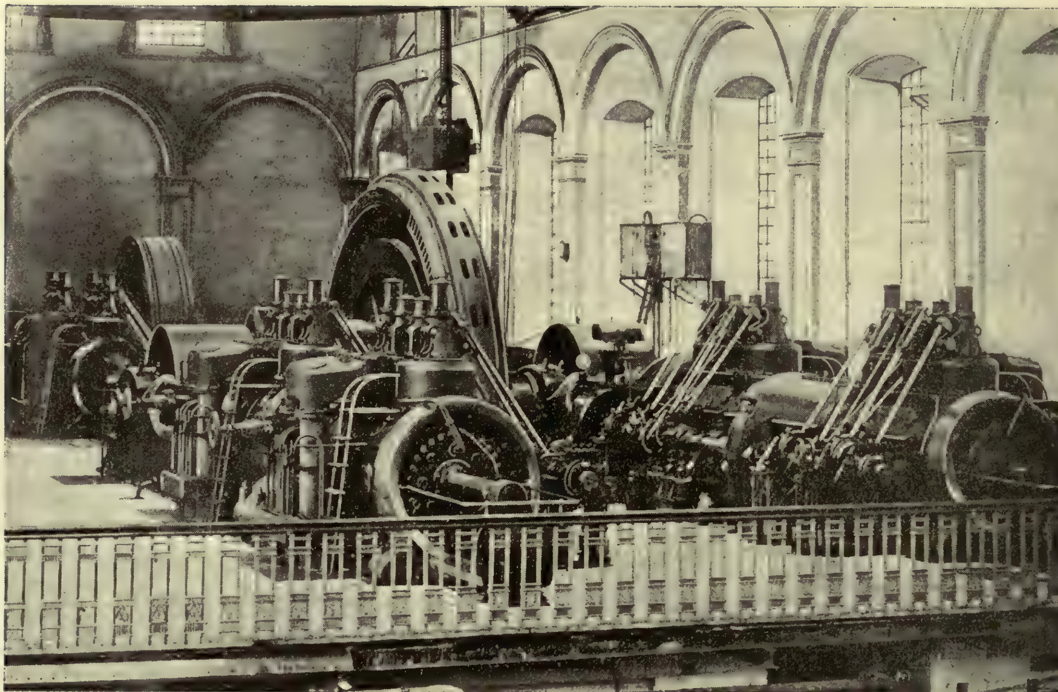
The Nürnberg Engines.

These engines were very large and heavy for a given power, even though the mean effective pressure in their cylinders ran very high. For this reason the Nürnberg Gas Engine Company have adopted the four-stroke double-acting type, which, while giving with one cylinder an impulse every revolution, avoids the use of external pumps. These engines are very useful for driving factories, blowing furnaces, and turning electric generators of a kind that at once demands and proves steady running. The company has supplied to this country engines of 1,200 and 2,400 h.p. These monsters, shown in Fig. 12, utilize the waste gas of coke ovens at the Powell Duffryn Steam Coal Company, Bargoed, to generate electricity.

Some makers have developed Clerk's idea in very large gas engines having cylinders closed at both ends and furnished with separate pumps.

The Two-stroke Engine.

In Fig. 14 we give a diagrammatic section of a Körting engine built by Messrs. Mather and Platt. This shows the air-pumps (AP[1] and AP[2]), the gas pumps (GP[1] and GP[2]), their valves, and their pipe connections with the two ends of the main cylinder, MC. The piston, P, is almost as long as its travel, so that it uncovers at the end of each stroke a ring of exhaust ports in the



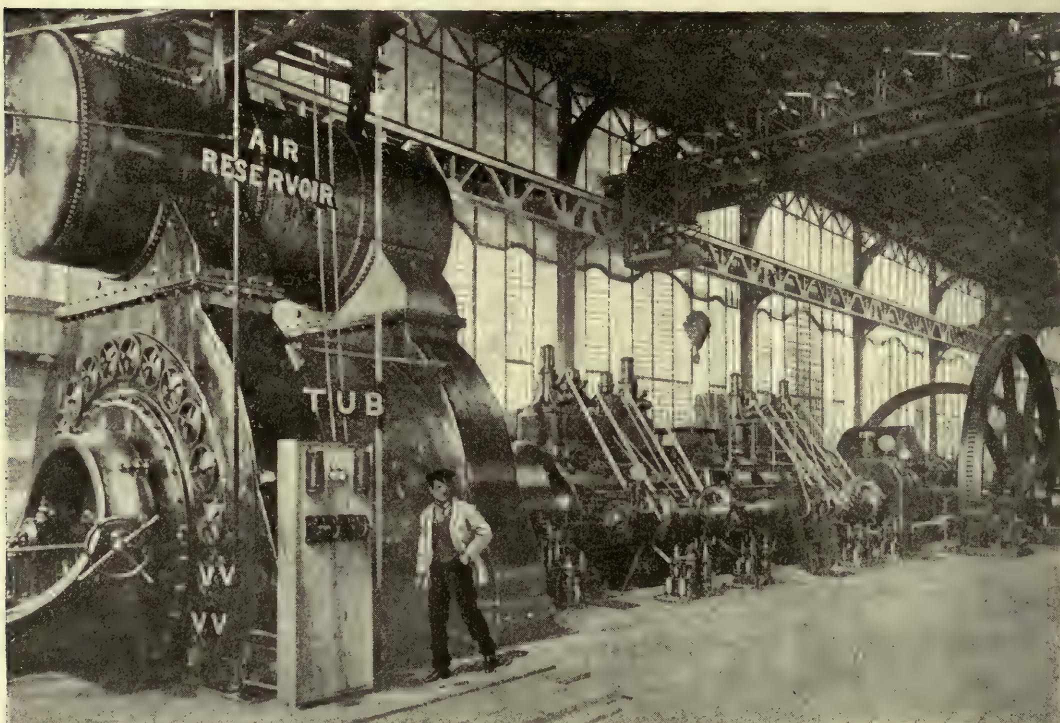


Fig. 12.—TWO NÜRNBERG GAS ENGINES OF 2,400 H.P. EACH, AND ONE ENGINE OF 1,200 H.P., WORKING AT THE POWELL DUFFRYN STEAM COAL COMPANY'S WORKS, BARGOED.

Fig. 13.—NÜRNBERG ENGINE OF 1,800 H.P. VV = valves of blowing tub. Blast furnace gas used.

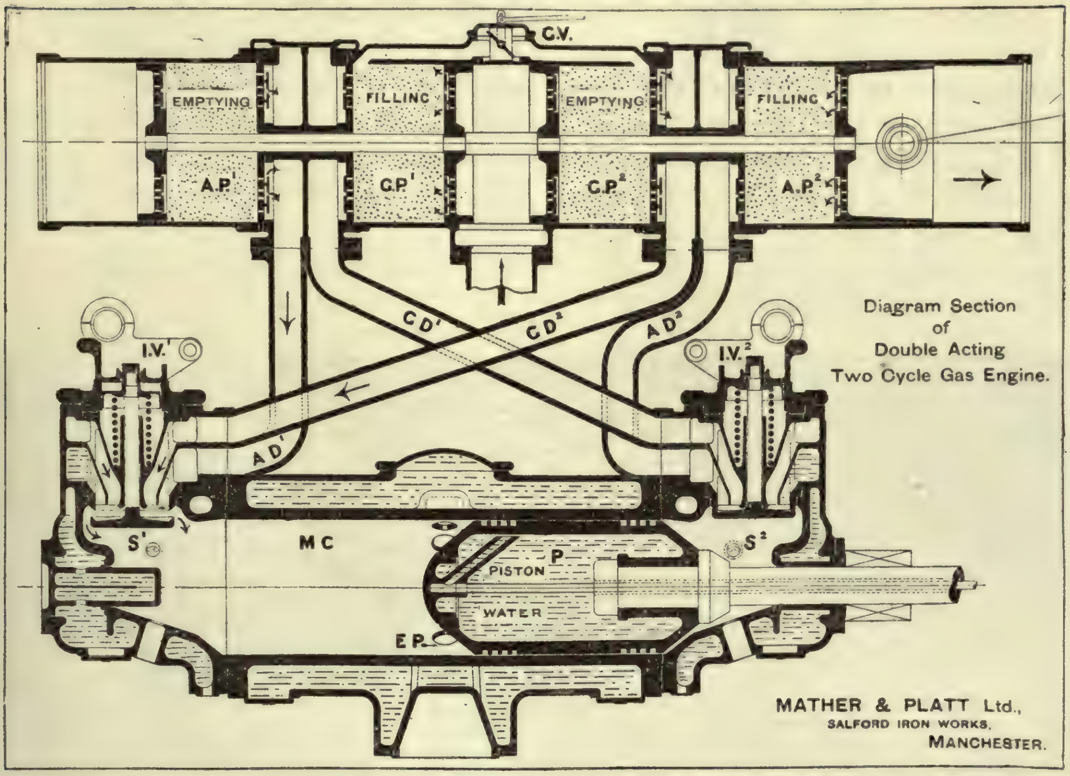


Fig. 14.—SECTION OF DOUBLE-ACTING TWO-CYCLE KÖRTING GAS ENGINE.

Showing Gas and Air Pumps, Pipe Connections, Water-cooled Piston, etc. (Messrs. Mather and Platt, Limited, Manchester.)

middle of the cylinder walls. When the central ports begin to open, one of the inlet valves (IV^1 or IV^2, as the case may be) also opens, admitting first air and then gas under pressure, which rapidly expel the burnt charge through the middle ports, until the latter are closed by the returning piston. The piston compresses the new charge and receives a fresh impulse when ignition (by a sparking plug, s^1 or s^2) occurs. Thus each stroke either way is a "working" stroke, and the engine develops nearly fifty per cent. more power than a steam engine of equal size and speed. Fig. 1 is a representation of a twin-cylinder Körting which for two years and more has performed the difficult work of driving a Lancashire cotton mill with perfect steadiness at a speed of 115 revolutions per minute. So satisfactory has it proved that another mill is adopting larger motors of the same type, with cylinders of 19¾ and 33½ inches bore and stroke respectively, developing 1,400 h.p. at 100 revolutions per minute.

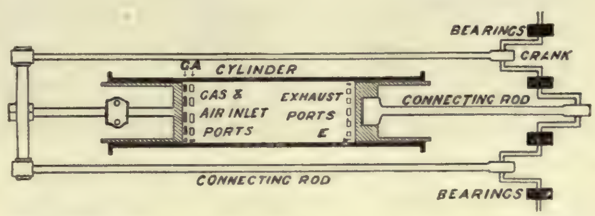


Fig. 15.—DIAGRAM OF OECHELHAUSER TWO-STROKE, DOUBLE-PISTON GAS ENGINE.

The Oechelhauser Engine.

An interesting arrangement of parts is represented in the diagram of an Oechelhauser engine built by Messrs. William Beardmore and Company (Fig. 15). In this case there is a single long open-ended cylinder, with two pistons moving in opposite directions simultaneously. One

piston operates a central crank on the shaft by an ordinary connecting rod, and from a heavy crosshead at the end of the fixed piston rod of the other cylinder run two long side rods to two cranks set in line on each side of the first crank. This disposition of the pistons and other moving parts gives perfect balance and smooth running.

Huge American Installations.

The Americans have followed closely the lead given by Germany. Probably the largest installation of blast-furnace gas engines in the world is that built by the De la Vergne Company of New York for the Lackawanna Steel Company. It includes sixteen 2,000 h.p. engines working

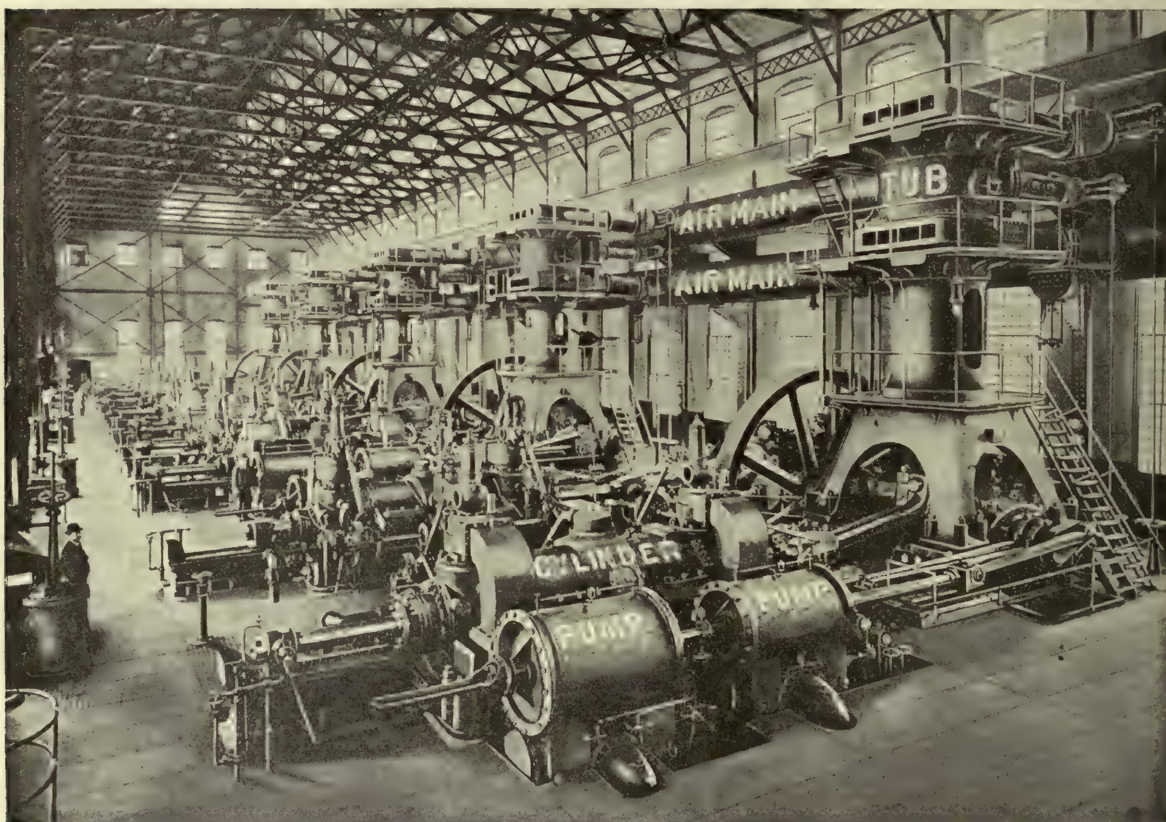


Fig. 16.—FIVE UNITS OF AN INSTALLATION OF SIXTEEN 2,000 H.P. KÖRTING ENGINES AT THE WORKS OF THE LACKAWANNA STEEL COMPANY, U.S.A.

At its extreme outward position one piston uncovers a ring of exhaust ports, E; the other uncovers first a ring of air ports, A, and then a ring of gas ports, G (marked in solid black). The fresh charge forced in by pumps through these expels the burnt charge at E. The Clerk two-stroke cycle being used, a working stroke is obtained at each revolution of the shaft.

as many huge 76″ by 60″ vertical blowing cylinders. Five of these engines are seen in Fig. 16.

The largest individual engines yet built develop about 3,650 h.p. These monsters have shafts 31½ feet long and 23½ inches in diameter to revolve 30-foot fly-wheels of enormous weight.

Referring back for a moment to Fig. 14,

you will notice that the cylinder is enclosed in a water jacket, and also that the piston itself is full of water. In very large engines it is necessary to provide water circulation in the pistons, and even in the large exhaust valves, as these parts contain so much metal that, but for artificial cooling, they would soon get so hot as to interfere with proper lubrication and cause preignition of the charge. This is especially true of a closed-in cylinder, heated at both ends, as in the case which we have before us. Jacketing of moving parts requires the use of water pipes flexibly jointed after the manner of those which convey oil under pressure to the crank pins and crossheads of large steam engines. Fig. 14 discloses a hollow piston rod encircling a smaller internal pipe. The cool water is forced in through the small pipe, and, after travelling through the piston, escapes by the annular space between the pipe and the rod.

Cooling Large Pistons.

It fell to the writer to make a test, several years ago, of the first engine ever driven by blast-furnace gas, and he said at the time that there was a regular Niagara of energy going to waste in the shape of unused gas. It has been estimated that the gas generated by the coke fed into a blast furnace is sufficient to operate the blowing engines, other machinery, and the stoves for heating the blast, and leave 1,500 h.p. over. At this moment, probably more than 500,000 h.p. is being developed in Germany by the gas engines using blast gases. Assuming half of the blast gas produced in Great Britain to be employed on heating stoves, there must remain some 2,000,000 h.p. continually available for lighting towns electrically, driving mills, working tramways, pumping water or sewage, and serving the general power purposes at iron and steel works for which coal is now consumed. The day will doubtless come when we shall make profitable use of

Wealth in Blast-Furnace Gas.

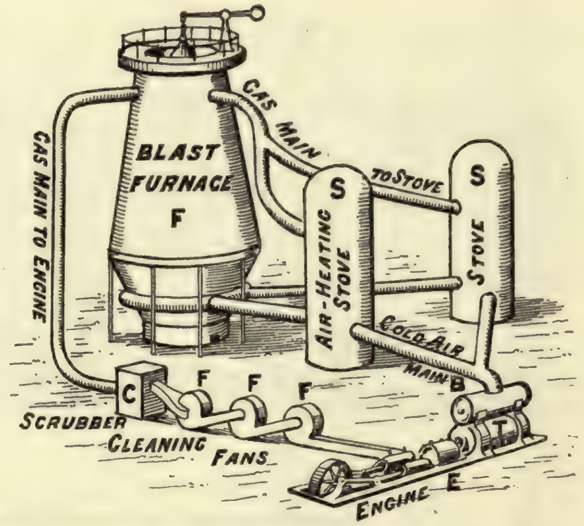


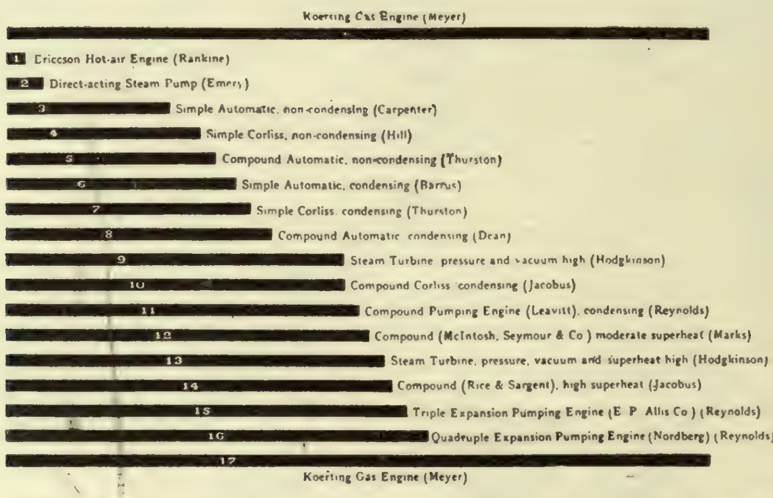
Fig. 17.—SKETCH TO SHOW CYCLE OF OPERATIONS WHEREBY A BLAST FURNACE AND A GAS ENGINE AID EACH OTHER.

this valuable by-product of one of our greatest industries. Until we do, we have no right to grumble over the too rapid exhaustion of our coal supplies. The blast furnace is really an ideal "producer," and every plant which makes use of its gas for power purposes furnishes a beautiful example of a continuous cycle of operations mutually assisting one another. We have had a sketch (Fig. 17) drawn to impress the nature of the cycle on the mind of the reader. Beginning at the furnace, F, where the gas comes into being, we follow it through the gas main to C (the scrubbers), and then through F F F (a series of cleaning fans, described on a previous page) to E (the engine), where it does the work necessary to drive the blowing tub, T. The tub pumps the blast air through the air main, B, to S S, the stoves in which it is heated before delivery to the blast furnace. The gas indirectly supplies the air, which contributes in turn to the formation of gas. So there is a fair give-and-take all round.

An Interesting Cycle of Operations.

The writer hopes that the above account of the growth of the gas engine from a small affair of a few horse-power to the monster of

to-day—with great possibilities still awaiting it—will enable the reader to appreciate the importance of Mr. Thwaite's discovery. That famous laboratory test of his has had results which have affected the welfare of a great number of people, and can be valued properly only by the expert. Large fortunes have been realized by the builders of blast-furnace gas engines. It is sad to think that, like many another inventor before him, Thwaite, the ultimate cause of these fortunes, should have reaped no material advantage for himself, but only the plentiful worry and disappointment which doubtless hastened his premature death.



COMPARISON OF HIGHEST THERMAL EFFICIENCIES REPORTED BY VARIOUS AUTHORITIES.

(Referred to indicated horse-power.)

The heavy lines indicate the proportionate efficiency in horse-power of various types of engines using the same amount of heat energy.

THEIR DESIGN AND CONSTRUCTION.

BY HARLEY H. DALRYMPLE HAY, M.Inst.C.E.

PART I.

The Deep-level Railway System of London is so unique that the following account, from the pen of an Engineer who has been associated with the construction of several of the "Tubes," cannot fail to be of general interest.

THE terrible congestion of traffic in the streets of the world's greatest city, and the need for more rapid transit than could be afforded by road vehicles, led to the construction of the Metropolitan Railways of London. These were laid out at a shallow depth, and were formed either in open cutting between retaining walls or by the process of cut-and-cover under roads. Existing buildings had to be underpinned or otherwise strengthened at many points; and the cost of doing this, added to that of buying property and way-leaves, granting compensation, and prosecuting the actual engineering work under great difficulties, discouraged the immediate extension of underground traffic facilities.

Need for Relieving the Congestion of London Traffic.

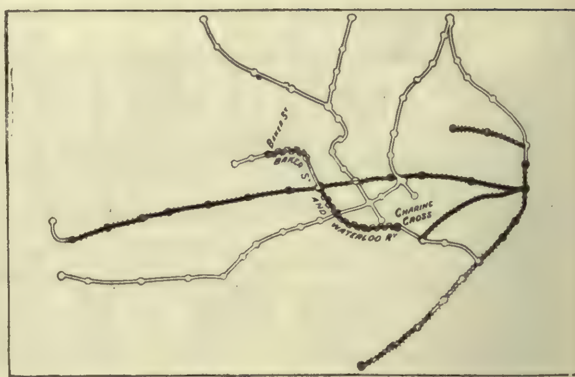
The present system of deep-level "tube" railways, with iron-lined tunnels, has, at least indirectly, its origin in the need for improving communication between the two banks of the Thames. In 1823, Marc Isambard Brunel commenced the Old Thames Tunnel, which, after enormous difficulties had been overcome, was completed in 1840. Brunel was the first engineer to use a movable *shield* to protect the working face during excavation and while the tunnel lining was being put in behind it.

In the year 1862, while constructing the piers of Lambeth Bridge by means of cast-iron cylinders sunk vertically into the London clay, Mr. P. W. Barlow, F.R.S., perceived that by using a shield of improved design—so that it should advance as a whole instead of by parts, as did Brunel's—in conjunction with a cast-iron lining, tunnels might be driven through the London clay as easily as cylinders could be sunk. He therefore proposed a system of "omnibus" subways, the first instalment of which was realized in the small tunnel, named

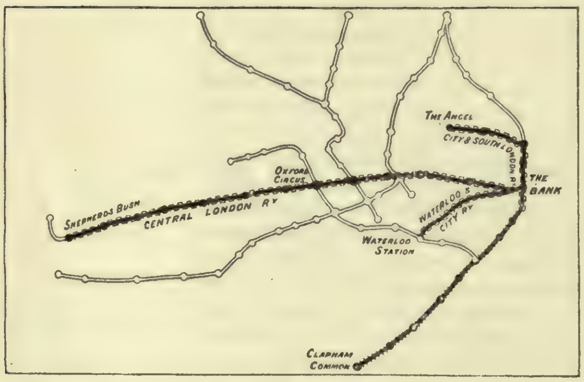
Barlow's Omnibus Tunnels.

MAP SHOWING THE DEVELOPMENT OF LONDON TUBE RAILWAYS AT THE END OF 1890.

The heavy black line indicates completed construction; open lines signify future developments.



DEVELOPMENT AT THE END OF 1902.



DEVELOPMENT AT THE END OF 1900.

DEVELOPMENT AT THE END OF 1904.

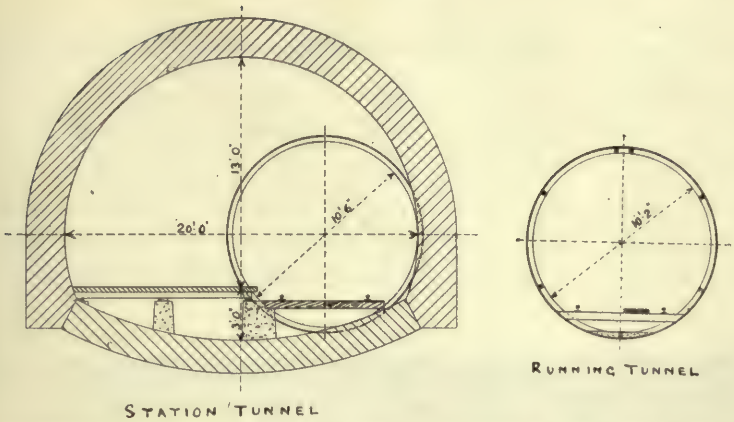
DEVELOPMENT AT THE END OF 1906.

Note.—Additions made to the lines shown in the previous map are indicated by a zigzag line, thus:—

the Tower Subway, driven under the Thames near the famous fortress. The engineer of this tunnel, which has an internal diameter of 6 feet 7 inches, was Mr. J. H. Greathead, whose invention of the tunnelling shield named after him entitles him to be regarded as the practical author of the "Tubes" of London. The principle of the shield will be described on a later page.

The Tower Subway.

With the help of this device, the tunnel was driven at a maximum speed of nine feet per day, work being carried on continuously. For a short time after the opening of the subway in 1869 passengers were transported under the Thames in a small car operated by a cable. Subsequently, as the scheme did not pay its way, the steam-worked lifts giving access to the tunnel were replaced by spiral staircases, and passengers had to walk from one side of the river to the other. The opening of the Tower Bridge in 1898 led to the subway being closed to traffic.



SECTIONS OF STATION AND RUNNING TUNNELS ON CITY AND SOUTH LONDON RAILWAY.

A bolder employment of Greathead's method led to the construction, during the years 1884–1890 of the City and Southwark Subway from King William Street, City, to the "Elephant and Castle" on the south side of the river, now known as the City and South London Railway. With the extensions made from time to time, it now has a total length of over seven miles, and reaches from Euston in the north to Clapham in the south. It was originally intended that this line should be worked by an endless cable, but the rapid progress in electric traction caused the latter form of power to be substituted, with excellent results.

The City and South London Railway.

On the opening of the first section of this railway, it was realized that Mr. Greathead's methods could be applied at a comparatively small cost to the construction of deep-level lines through the thick stratum of clay which underlies the greater part of London. The year 1892 witnessed the birth of a number of separate and independent schemes for "Tubes," and in 1893 the following were authorized :—

London "Tubes."

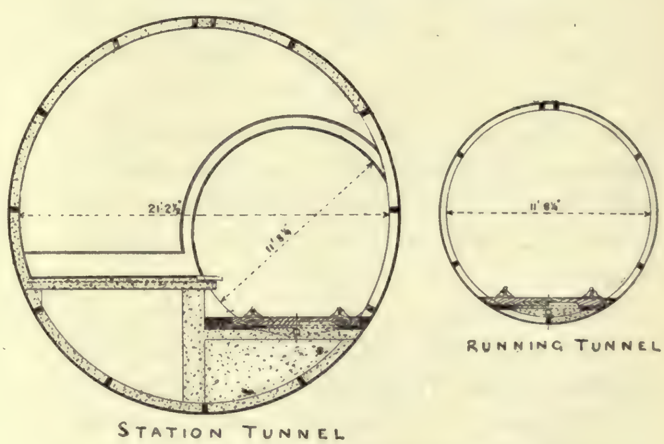
	Approximate length in miles.
The Central London Railway (Shepherd's Bush to the Bank of England)	$6\frac{1}{2}$
Waterloo and City Railway	$1\frac{1}{2}$
Great Northern and City Railway (from Finsbury Park to Moorgate Street)	3
City and South London extension to Islington	3
Charing Cross and Hampstead	5
Baker Street and Waterloo (The "Bakerloo")	3

The sketch maps on p. 228 show the progress, at different dates, of the construction of these various lines. At the present time there are open for public traffic over forty miles of double-line Tube railways.

The gauge of the permanent ways of the Tubes is standard—that is, 4 feet $8\frac{1}{2}$ inches. The size of the tunnels varies, however, so that the rolling stock of the different companies is not interchangeable. Thus, the first section of the City and South London Railway had tunnels 10 feet 2 inches in diameter, whereas on the last extension of this system the diameter has been increased to 11 feet 6 inches.

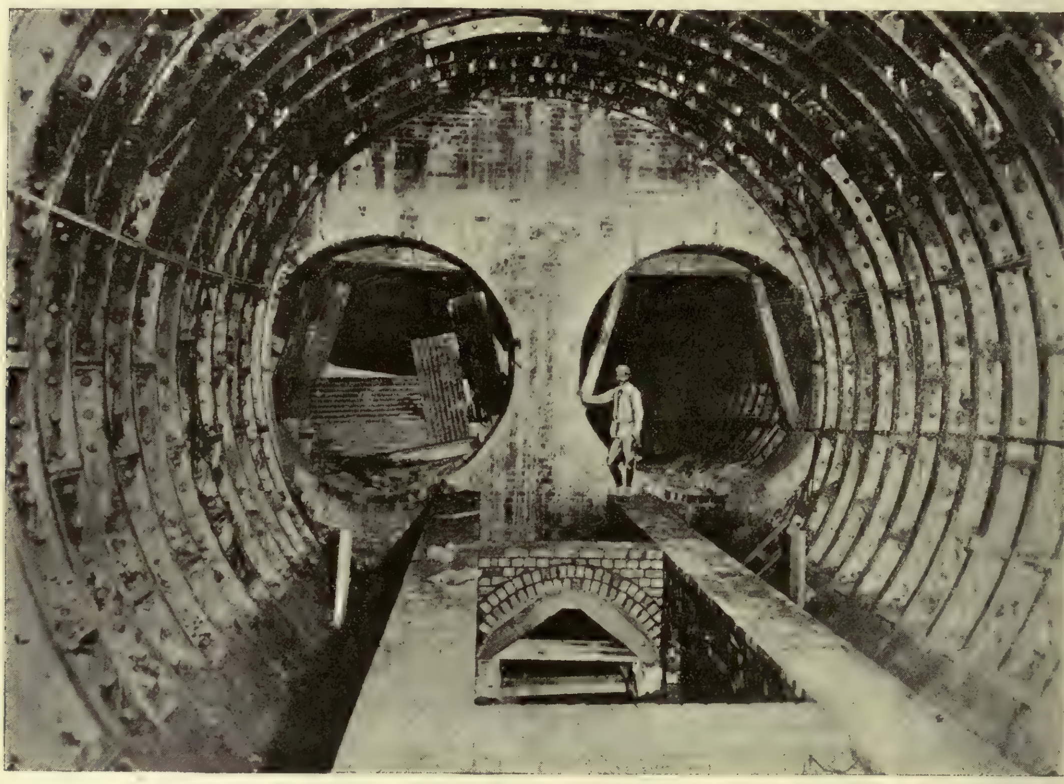
Diameter of Train Tunnels.

In the case of the Great Northern and City Railway, which was designed to assist and relieve the local passenger traffic of the Great



SECTIONS OF STATION AND RUNNING TUNNELS ON WATERLOO AND CITY RAILWAY.

Northern Railway and afford a new and direct means of access to the heart of the city, the tunnels between stations (the "running" tunnels) have a diameter of 16 feet. We may remark in passing that these tunnels were formed originally as complete iron tubes, and that afterwards brickwork in cement was substituted for the lower half of the metalwork. This composite form of construction was expected to minimize noise and vibration and give a more elastic roadbed, but the results have not justified the extra expense incurred.



STATION TUNNEL ON CENTRAL LONDON RAILWAY BEFORE PLATFORMS WERE COMPLETED, SHOWING TWO RUNNING TUNNELS.

Of the other Tube systems generally, it may be said that their tunnels have a diameter varying within a few inches of 12 feet, and that the diameter is increased on sharp curves to give the extra clearance needed for a long bogie car.

THE MATHEMATICS OF TUNNELLING.

The uninitiated wonder how engineers manage to drive their tunnels on the exact lines assigned to them, and how sections of the same tunnel, started from two or more points, and constructed simultaneously, can be made to join up with such precision that the errors of alignment seldom exceed a small fraction of an inch. The mystery deepens when it is brought home to them that the tunnels curve here to the left, there to the right, and are constantly changing their level in accordance with the requirements of the gradient or rights of way. Under a broad street the two tunnels of a railway may run side by side, whereas under a narrow road it often becomes necessary to carry one vertically above the other, and this change of relative position

means the introduction of some complicated curves.

As a matter of fact, the methods adopted require, so far as calculations are concerned, the use of but elementary trigonometry, coupled with the greatest care in taking all measurements—not only underground, where errors can so easily be made in the darkness of the tunnel, but also on the surface, where observations are much hindered by passing vehicles and human beings. The difficulties incurred can be appreciated fully only by those who have had to do the work under such trying conditions.

SETTING OUT A TUNNEL.

The first task of the engineer is to determine the route to be followed by referring to an ordnance survey map. Then, armed with steel tapes, level, theodolite, and other apparatus, he proceeds to run a series of *traverse lines* over the actual surface, preferably along

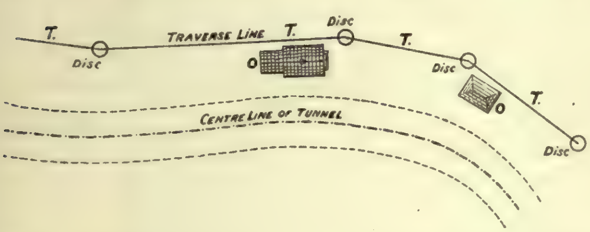


Fig. 1.—DIAGRAMMATIC PLAN OF TRAVERSE LINES (T T) CARRIED ROUND OBSTACLES (O O).

At each angle a disc is let into the surface of the ground, to enable the lines to be found by theodolite when required.

the pavements of the streets under which the intended tunnels are to be constructed. Each traverse line extends for such a distance as can be commanded conveniently by observation instruments from one end. At each extremity of the line metal discs are let into the pavement, and marked with a punch in the centre to indicate the points between which measurements are to be made subsequently, in order to determine the respective lengths of the line. To enable the lines to be plotted on a plan, the angle between each pair is accurately measured with a theodolite set up over the punch-mark on the disc at the point where the two lines intersect.

The measurement of distance is done with a 100 feet steel tape.

As the length of the tape varies slightly with the temperature of the air, due allowance is made for this when recording the readings. Also, since the surface of the pavement is more or less uneven, and the discs at the end of each traverse line may be at different levels, it is necessary to take the level of the ground at the end of each 100 feet tape measurement, or at any intermediate points where a change in the evenness of the surface occurs, so that the oblique distances measured between the several pairs of discs may be converted by calculation into their true horizontal distances. These facts are mentioned to show the need for exactness.

The Plan.

A plan, generally drawn on a scale of 30 feet to the inch, is next prepared, showing the traverse lines and all details of pavement, kerbs, building-fronts, etc., that may be necessary. To this plan are added the positions of the shafts, stations, and tunnels, and particulars of the relations between the traverse and tunnel lines, as the first afford the basis for transferring the second below ground.

Then follows the actual transference of the tunnel centre line from the plan to the site of the work itself. This, of course, cannot be done until the shaft, say, at the station site has been sunk to full depth and a cross heading has been driven from it to a point on the path of the future tunnel.

The operation will be more easily understood with the help of Fig. 2. T T is a traverse line. To the left of it is a shaft, S, which has been sunk, and a cross heading, H, driven from it. At a convenient point, A, on T T, a disc is let into the surface, and the angles made by T T with AC, a line crossing the shaft,

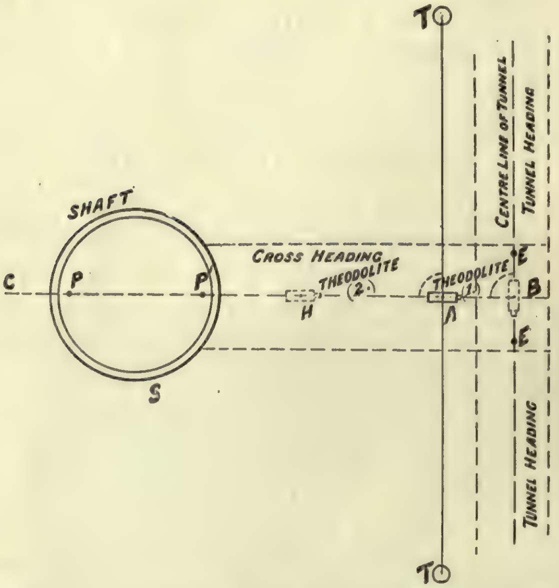


Fig. 2.—DIAGRAM TO SHOW HOW THE CENTRE LINE OF A TUNNEL IS TRANSFERRED FROM THE SURFACE INTO THE WORKINGS.

Full lines on surface, dotted lines below ground.

are carefully noted. A heavy plumbob, P R, is now suspended on the farther side of the shaft, in line with C A; and P^1R^1 on the nearer side of the shaft, in the same line. The plumbobs are immersed in buckets of oil or water at the bottom of the shaft to prevent their swaying about. (Fig. 3.)

The theodolite is now transferred from A to the bottom of the tunnel, and adjusted until its axis is in line with the plumb wires. As the distance from P to B (a point on the centre line) on the surface is known, a point B^1 in the heading exactly below B is easily found by measurement from P R. Over this point the theodolite is set up, and turned till its axis makes with the plumbob line an angle ϕ, equal to the angle which the tunnel line makes on the plan with the line C A produced, which is vertically over the cross heading line. Points, E E, are then fixed whereby the tunnel headings may be guided.

Transferring Lines below Ground.

The exact position and direction of the tunnel line so set out are not finally determined till the processes described have been repeated several times to eliminate errors.

Where everything is straightforward, the work, though tedious and very trying, is not difficult. But where calculations have to be transferred down a working shaft situated in an awkward position, such as the mid-river shaft of the Waterloo and City Railway, and where direct measurements by tape are impossible, the business becomes much more complicated, and an engineer has to resort to elaborate trigonometrical triangulation to fix distant points and base-lines from which to make and check his calculations.

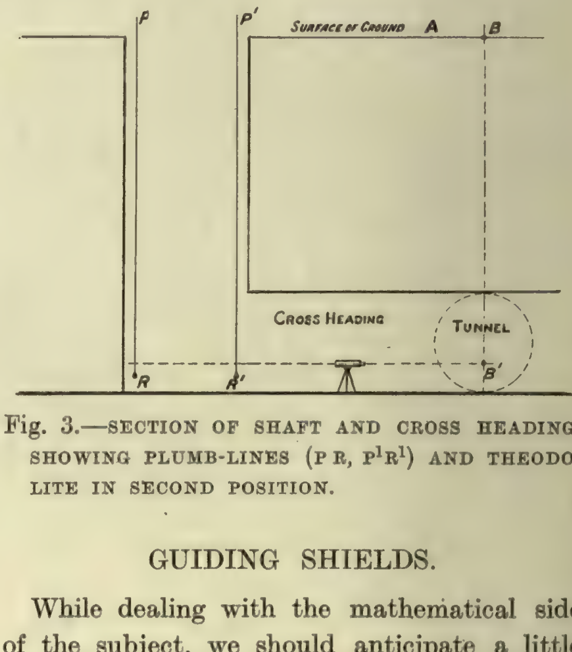


Fig. 3.—SECTION OF SHAFT AND CROSS HEADING, SHOWING PLUMB-LINES (P R, P^1R^1) AND THEODOLITE IN SECOND POSITION.

GUIDING SHIELDS.

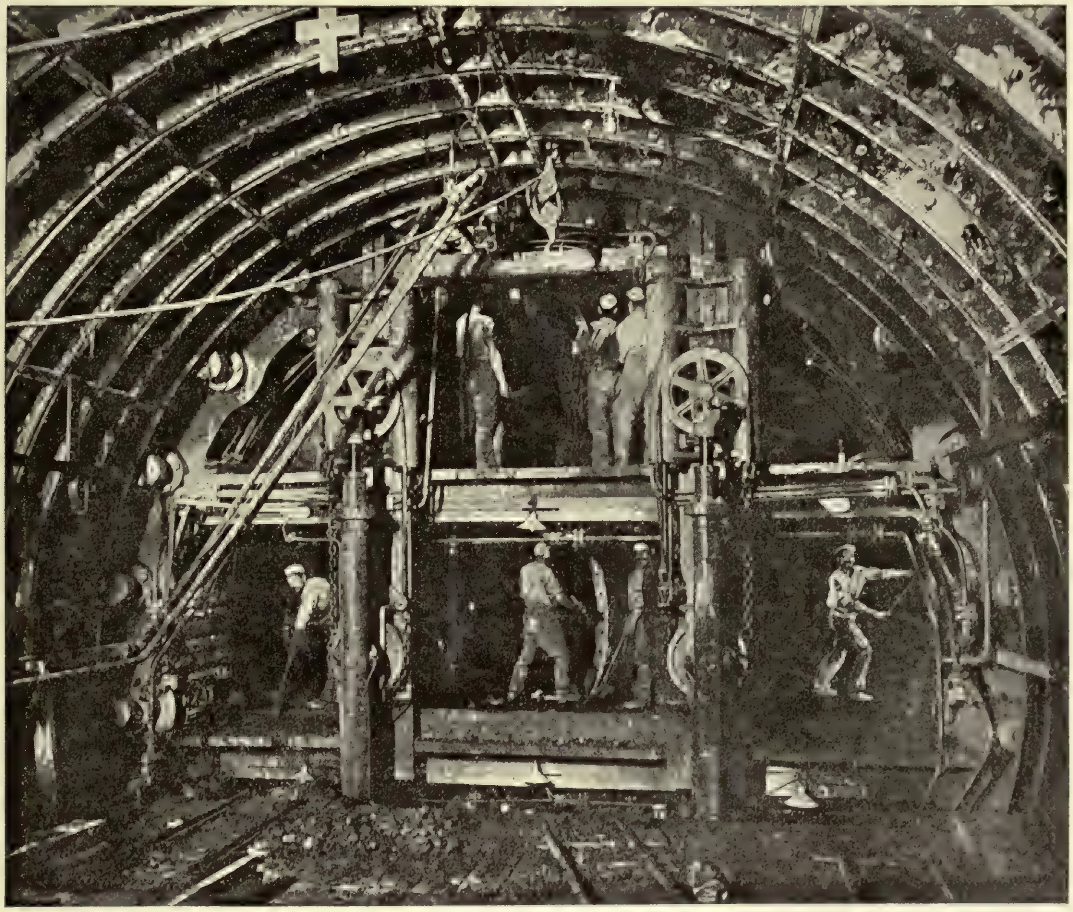
While dealing with the mathematical side of the subject, we should anticipate a little and refer to the methods of steering a shield through the ground—first, on the "straight;" secondly, round a curve.

"Zero marks" are made on pieces of wood fixed to each side of the tunnel, at about the level of the horizontal diameter, so placed that the line joining the two marks is square to the centre line of the tunnel.

Two rods, divided into feet and inches, are attached at one end to the sides of the shield, and at the other rest on the pieces of wood. As the rods move with the shield, while the

zero marks are fixed to the tunnel lining, it can be seen at a glance, when the shield is actually advancing, whether the advance is even. If the readings on the rods do not tally, the ganger in charge of the shield corrects the error by manipulation of the rams.

The same principle, somewhat modified, is used to drive a shield round a curve. In this case the spaces between the division marks on the rods are respectively proportioned to the radii of curvature of the two sides of the tunnel. The conventional diagram (Fig. 4) will make my meaning clear. Suppose the radius of the outer wall of the tunnel to be 5 yards, and that of the nearer wall 4 yards, then the divisions on rod A must be to the divisions on rod B as 5 is to 4; and so long as the marks on the rods keep even relatively to the zero marks on the tunnel, the shield must be following the correct curve.



STATION SHIELD ON WATERLOO AND CITY RAILWAY.

(Photo, The Woodburytype Photographic Printing Co.)

Steering Round a Curve.

Useful as the guide rods are, they do not entirely obviate the need for an independent means of checking the position of the shield.

Offsets.

But before going further we must pay some attention to Fig. 5. T T is a line tangential to the centre line of the curve—that is, at right angles to the radius of the curve—at O. Knowing the radius of the curve, we can find successive points P^1, P^2, P^3, P^4, etc., on the

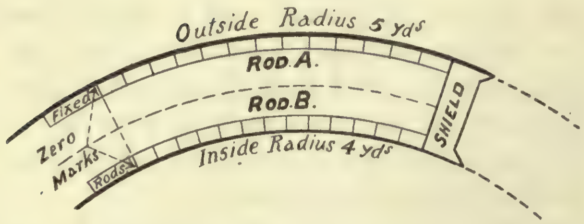


Fig. 4.—DIAGRAM TO SHOW HOW A SHIELD IS GUIDED ROUND A CURVE BY MEANS OF PROPORTIONALLY GRADUATED RODS.

curve to the right of O by making "offsets," S^1, S^2, S^3, S^4, etc., of calculated length, at right angles to the tangent, at points B^1, B^2, B^3, B^4, etc. The engineer has to calculate

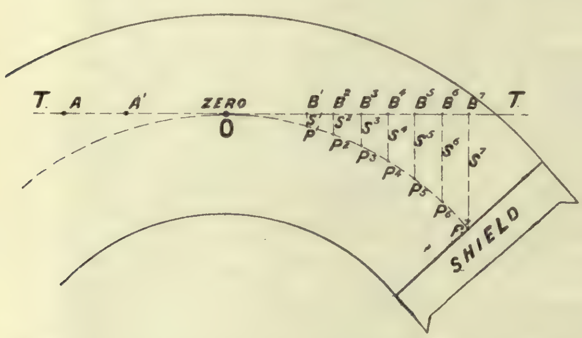


Fig. 5.—DIAGRAM ILLUSTRATING HOW THE POSITION OF A SHIELD IS CHECKED BY "OFFSETS" S^1, S^2, S^3, ETC., FROM A TANGENT LINE.

the respective lengths of these offsets and make a table of them for the ganger in charge; also to provide plumb-lines at points A, A^1 on the tangent for sighting the line. When the shield has been driven, say, to the position shown in Fig. 5, the ganger measures the distance from O to the centre of the shield, marked on a piece of wood called a "fiddle." Looking at his table of offsets, he finds that the offset from the tangent to the centre should be of such and such a length. He then gets the wires at A, A^1 in line, and an assistant makes a mark on the "fiddle," and measures from that mark to the centre of the shield. If the measurement equals the theoretical offset, the shield is travelling correctly; if not, the difference indicates how far the shield is out of line, and informs the ganger what must be done to put it right again.

It is obvious from Fig. 5 that a tangent line must eventually meet the side of the tunnel, and that offsetting from it cannot be continued indefinitely.

Setting out Tangents.

As soon, therefore, as the need arises, the engineer sets out another tangent from which offsetting may be continued. In Fig 6, A O B represents the first tangent, and S the last offset made

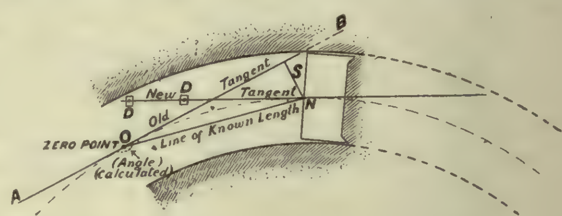


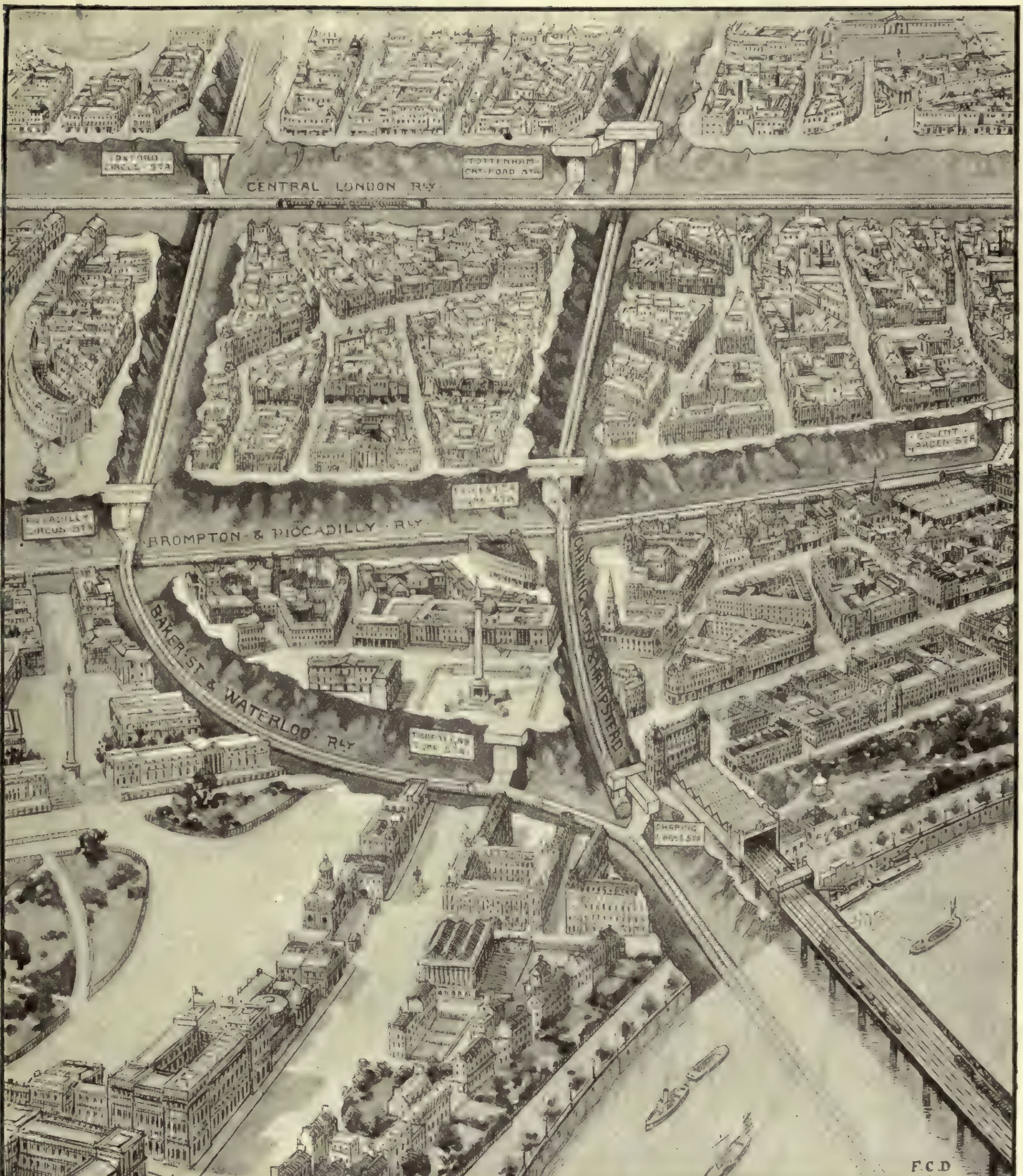
Fig. 6.—ILLUSTRATING THE METHOD OF OBTAINING A NEW TANGENT LINE.

from it. The engineer has to line out a new tangent at N. At N is built a stage for the theodolite—one already exists at O, the old tangent point. When the distance from O to N has been measured with a tape, the point N can be definitely fixed, as calculations show what the size of the angle A O N must be to allow both O and N, the ends of a chord of a circle of known radius, to be in the circumference. The theodolite is moved to N, and an angle, O N D, is turned off equal to B O N, the complementary angle to A O N. Points, D, D, are fixed with plumb-lines, and the line joining them gives, when produced, the new tangent. Offsetting is then continued from the new zero point, N, and further tangents are established in the same way as required.

So far lateral guidance only has been considered. To keep the shield on the level or on a gradient, its movements are checked by

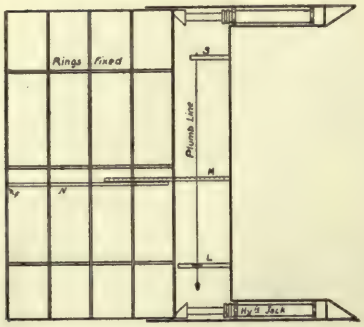
Vertical Steering.

a plumb-line hanging from a support fixed to the top of the shield. A two-foot rule held square to the shield near the bob shows whether the shield is vertical, or to what



A PERSPECTIVE VIEW OF THE LONDON TUBE RAILWAYS.

Showing the earth cleared away on the line of the Tubes.



A shield is steered vertically by means of a plumb line and a graduated "plumb stick" held against the shield.

extent it may be "out of plumb." In order to determine whether the level of the shield be correct, two inverted T-shaped rods are suspended from the roof of the tunnel, the cross bars of the T's being fixed at a predetermined height. When the shield is at its correct level a mark on the diaphragm of the shield is in line with the line joining the upper surfaces of the T-pieces.

SHAFT-SINKING.

The shafts at the stations for the lifts and stairs are in all cases formed of cast-iron circular rings of a pattern similar to those used for the tunnels. The shafts to contain two lifts have an internal diameter of 23 feet, and those for three lifts one of 30 feet. The stair shafts vary in diameter from 16 feet to 18 feet. In one or two cases lift shafts of 16 feet and 20 feet internal diameter have been adopted for single lifts.

The method of sinking the shafts is entirely governed by the nature of the ground and the probability of encountering water. Where the ground is good—that is, where it contains no water—the method of "underpinning" is applied.

"Under-pinning" Method.

This consists of excavating below the lowest ring of segments in position, and bolting to the under side of that ring, in the space so excavated, a new ring of segments, and so executing the work downwards ring by ring. The excavation always has a diameter somewhat larger than that of the shaft, so that the segments may be easily erected in position. This results in a small annular space being formed outside the ring, and it becomes necessary to fill with lime grout the space so formed between the outside of the shaft and the ground.

Where, however, the ground is heavily charged with water, as in the lower portions of the gravels overlying the clay, one or other of two further methods is generally adopted.

Use of a Cutting Edge.

By one method a cutting edge is securely bolted to the lowest ring in position. The ground is then excavated over the general area of the shaft, and to make it sink into the ground large timber baulks are placed across the top of the shaft and heavily loaded, so that the additional weight may overcome the friction between the sides of the shaft and the ground, as well as the cutting and wedging resistances offered by the shaft in its descent.

This method is slow, and necessitates the removal of the load every time a fresh ring has to be erected on the top of the shaft, after it has sunk a sufficient depth to need an addition. Moreover, if the shaft does not sink evenly, it is often necessary to weight it more heavily on one side than on the other. This often results in the segments being fractured. Such water as finds its way into the shaft is pumped out.

The other method—the one now usually adopted when the influx of water is not too great—is to construct the shaft by underpinning. The ground outside the shaft is supported by poling boards, and the space between the boards and the ground is filled in with Portland cement grout forced in under pressure.

Then the iron segments are placed one by one, and the space between them and the poling boards is similarly grouted. Note that

by this method the timber used is left permanently in the ground.

In the case of a stairway shaft at Kennington Road Station, a shield of simple form was used. The excavators loosened the ground at the cutting edge of the shield by working it with bars and picks; while ten bottle screw-jacks, placed round the circumference, one at the junction of each pair of cutting-edge segments, were screwed so as to force the shield down into the gravel, the upper ends of the jacks bearing against the bottom of the last shaft ring. When the shield had been advanced sufficiently for an 18-inch-deep ring to be fixed, the screw-jacks were successively removed and replaced by the segments of the new ring.

The Shield Method.

The greatest success attended this method of working, which, it is believed, is quite novel as regards shaft-sinking in the manner effected and under the conditions named, for it was found that the shaft when completed was perfectly plumb from top to bottom.

There is every probability that, when engineers get to know of its feasibility, the shield method will find general favour, since even this small experience has proved the system to be cheaper, quicker, and better in every respect than the old-fashioned method of loading shafts, which in so many cases has been productive of considerable delays through the shaft being bound on one side or the other, and has also produced costly fractures of the shaft segments.

Its Success.

CONTRACTORS' ELECTRIC HAULAGE TRAIN. *(Photo, Bolas and Co., 5 and 7 Old Queen Street, S.W.)*

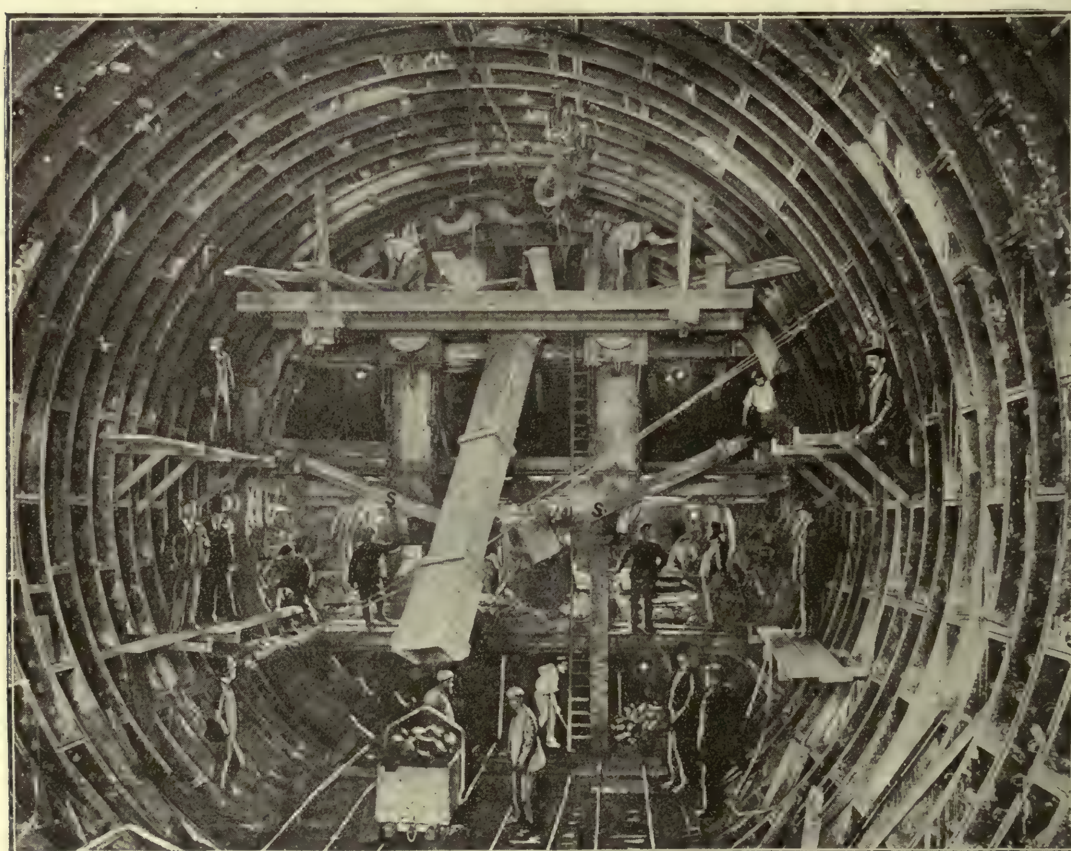
Fortunately, in none of the London Tube shafts has the influx of water been so great as to require the application of compressed air to exclude water during construction.

TUNNELLING.

A number of different methods of tunnelling were necessary under different parts of London to cope with the varying nature of the ground. For instance, although the bulk of the tunnelling was executed in the London clay, water-bearing gravels or sands were encountered at certain points on each of the railways.

Where the tunnels were in London clay, the Greathead shield and the rotary shield were adopted, except for some very short lengths of tunnel, in which the work was executed without a shield at all, to save the expense of putting in a shield to work for but a short time.

In water-bearing strata two methods of tunnelling were employed—namely, the Greathead "assisted shield" method and the "clay pocket" method. Each of these methods will therefore be described separately.



STATION SHIELD AT WORK ON CITY AND SOUTH LONDON RAILWAY. (*Photo, F. Milner.*)

Observe the long wooden shoot for excavated material, and the hydraulic segment erectors S S.

The London clay is almost an ideal material in which to construct a tube railway, as it contains no water and is easy to excavate. The work being executed very quickly, the clay has no time to swell and bring undue pressure on the finished tunnel, which, unlike a brick tunnel of the old type, attains its full

strength immediately the iron segments of a ring have been bolted up and the space outside them grouted.

Tunnelling with the Greathead Shield in London Clay.

The Greathead system of tunnelling in the clay consists of driving a heading by hand labour in front of a shield, as shown in several of our illustrations, and utilizing for purposes of excavation the hydraulic power by which the shield is propelled, so that in advancing it causes the face of the excavation to be broken up by a series of short timber piles placed between the shield and the face of the excavation, the materials so dislodged being removed by hand labour after the shield has come to rest.

Excavating the "Face."

Owing to the extremely limited space directly in front of the shield, between its diaphragm and the cutting edge—namely, some 15 inches—at certain stages of the work it is not possible for more than one miner, or two at most, to excavate. Consequently, in order to get more men "into the face," the heading referred to above, representing about twenty-eight per cent. of the total area of the face, is always driven forward of the work, while the advancing shield shortens the heading at the back.

In order to utilize the pressure of the rams to the fullest advantage for the purpose of excavation, the timber piles mentioned are placed round the entire circumference of the bull-head casting, slanting slightly upwards.

When all is ready, the two nearest supports at the shield end of the heading are removed, or in some cases only slackened, so as to allow the face to collapse towards it; and the instant that hydraulic pressure is applied to the rams the shield advances, causing the piles to penetrate the face and so detach from it large lumps of clay. In this manner the material is completely broken up by the piles and falls into the "length." It is subsequently removed by the miners and cast on to the stage at the back of the shield, and thence shovelled into skips for removal. Enough has been said to show that the piles form an extremely valuable adjunct to the shield when tunnelling in the London clay.

Clay stones frequently occur in the London clay in beds of varying thickness or in isolated lumps, and these have to be removed by hand, as the piles cannot break them up.

The maximum speed of advance attained is generally about 10 feet, or a little over, per day of twenty-four hours in the case of the small 11 feet 8¼ inch or 12 feet 7 inch diameter tunnels between the stations.

The Greathead Shield.

Referring to the design of the Greathead shield: It consists of an outer cylindrical shell of steel two inches larger in diameter than the external diameter of the tunnel, the total length of the shield from cutting edge to tail being 7 feet. There are seven 7-inch hydraulic rams placed within a cylindrical casting, to which they are connected by stout bolts. The stroke of the rams is 22 inches, or 2 inches longer than the length of a ring of tunnel lining. Each ram is capable of exerting a thrust of about 34 tons.

In the old type of shields, as used on the Waterloo and City Railway and the City and South London lines, the hydraulic pressure in the rams was produced by two hand-pumps, one on each side of the shield. For the Waterloo and City Railway, in the compressed air portion of the work, electrically driven hydraulic pumps were used with great advantage to the men; but in all the most recent shields a very admirable and compact type of compressed-air-driven pump is used. This, although noisy in action, is of the greatest advantage to the men, as it relieves them of what used to be a period of very hard work every time they had to "pump up the shield" by working the long pump handles.

The piston rods of the rams fit into solid

iron heads, which thrust against a circular timber rib placed between them and the flanges of the last-placed ring of iron lining. The function of this rib is to distribute the thrust of the rams over the ring, and act as a stop to prevent the grout from pouring out into the shield when the annular space between the ground and the exterior of the last ring of tunnel is being filled.

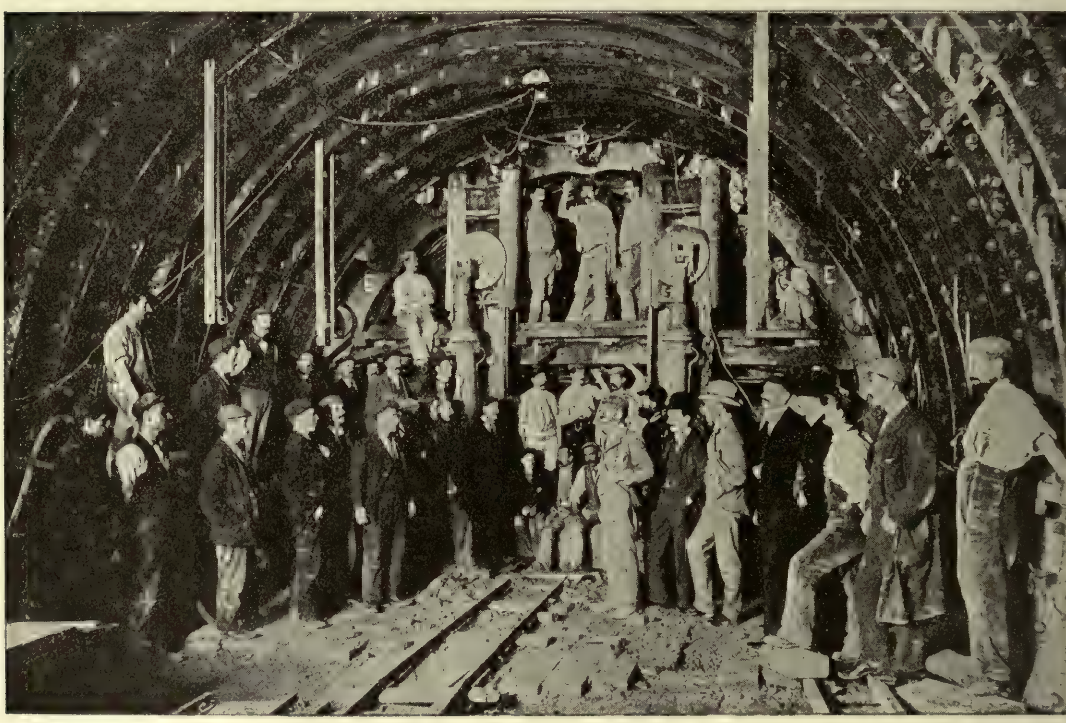
The "front end" of the shield, against which the cylindrical castings containing the rams abut, is formed of a stout casting made in four segments, and has an external diameter slightly larger than that of the rest of the shield.

This casting is splayed to receive the cutting edge, which consists of steel plates one inch thick, forming a continuous conical ring. The plates are splayed at the front end so as to form a sharp edge, and can be extended to cut wide of the shield when driving round curves.

The Cutting Edge.

The skin of the shield extends from within a few inches of the cutting edge, to which it is secured by set pins, to the tail of the shield.

(To be continued.)



ANOTHER VIEW OF A STATION SHIELD. *(Photo, F. Milner.)*

Note the ends of the $5\frac{1}{2}$-inch hydraulic jacks, E E, pressing on tunnel ring.

SEVEN VESSELS OF THE AMERICAN FLEET COALING IN PORT SAID HARBOUR.

The opening of this, the first of the great Ship Canals, entirely revolutionized sea communication between Europe and India and the Far East. The construction of the Canal was an engineering enterprise of the first magnitude, and its successful issue will ever do honour to the genius of the brilliant but ill-fated Ferdinand de Lesseps.

WHEN M. Ferdinand de Lesseps, the famous French diplomat and engineer, first conceived the idea of constructing an artificial waterway between the Mediterranean and the Red Sea, he often declared that every intelligent child, on seeing a map of Egypt, must ask his teacher why the road to India did not cross the Isthmus of Suez. But this question had certainly engaged the attention of the ancients, for a canal across the isthmus was actually constructed six hundred years before the Christian era, and served periodically as a waterway for small boats for upwards of fifteen hundred years.

Early Canals.

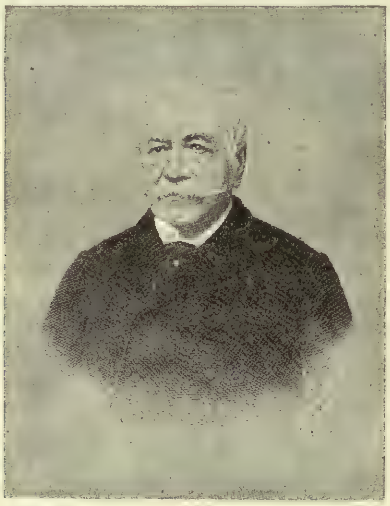
The Egyptian king, Rameses II., seems to have been the first to excavate a canal between the Nile delta and the Red Sea. This, having been filled up and become disused, was reopened by Darius I. of Persia. It was again allowed to fall into decay, to be once more cleared and made serviceable for the passage of vessels by the Arab conquerors of Egypt.

This ancient canal was really a very small artificial cut, a mere nothing compared to the present waterway, which has reduced the distance between India and Western Europe from 11,379 to 7,628 miles, thereby effecting a saving of at least ten days in the journey. As a colossal piece of engineering work, boldly conceived and daringly carried out, the Suez Canal takes high place. Even to-day it is the scene of fresh engineering triumphs. It is continually being widened and improved, and calls for the latest and largest machinery to effect this. Vessels making their way through the Canal sometimes become stranded and sink, completely blocking up the passageway. These wrecks have to be removed quickly, and the Canal Company maintains an elaborate and costly salvage fleet, whose business it is to raise sunken ships. Sometimes it is even necessary to blow up a vessel —dangerous and difficult work, as on no account must the banks be damaged.

M. de Lesseps was by no means the first

person of modern times to give attention to the question of making a waterway through the isthmus. Napoleon advocated the construction of a canal wide enough to admit the passage of ocean-going vessels. In 1798 he commissioned an engineer, M. Lepère, to examine and report to him on the practicability of the idea. This engineer virtually

Napoleon's Scheme.



FERDINAND, COMTE DE LESSEPS.
(*Rischgitz Collection.*)

put an end to the project for the time being by declaring that the surface of the Red Sea was nearly thirty feet higher than that of the Mediterranean.

As trade between Europe and India increased, the isthmus proved such an obstacle to rapid communication with the Far East that the British Government approved a scheme for an "overland route." This consisted of landing passengers and mails at Alexandria, transporting them by train to Suez, and there re-embarking them for India. At best, however, it was but a makeshift. It simply shortened the journey for Indo-European travellers and accelerated the mails—that was all. A road to India across the isthmus, to be of the greatest service to shipping in general, and to Great Britain in particular, must be such as would not necessitate the disembarking and re-embarking of passengers and mails, and would permit merchandise also to be carried without the trouble and expense of transhipment. A maritime canal, wide and deep enough for ocean-going vessels, was the only plan which would meet all the necessities of the case. Was a maritime canal practicable? and would such a canal, if constructed, be financially profitable? These were the questions which M. Ferdinand de Lesseps debated with himself and with the world many years. An absolute affirmative could not be easily obtained by the great engineer; he had to win it patiently, by persuasion from his friends, by the logic of facts from his foes.

The Overland Route.

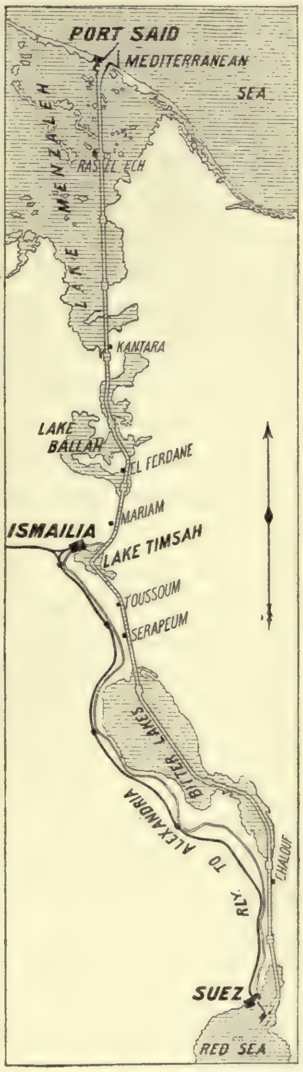
M. Ferdinand de Lesseps.

Two points of great importance were quickly decided by M. de Lesseps: first, that it was undesirable to follow up Napoleon's idea of restoring the disused canal; second, that the shortest and most direct practicable line must be drawn between the Red Sea and the Mediterranean. The route being chosen, questions of considerable interest and no little difficulty confronted him. Was the sea-level about the same at both the two extremities of the proposed Canal? or was there, as had generally been supposed, a difference of level so great that the Canal would be literally flooded as soon as it was opened? Would the process of "silting up" choke the Canal? Was it possible to construct a port and keep the entrance clear on the Mediterranean side of the Canal? When these questions were disposed of, there were others ready to present themselves; but those mentioned were the most difficult, except, perhaps, that of finding the tens of thousands of labourers which the work would require, and of feeding them in such a "desert place" when they should be found.

For the solving of some of these problems,

Surveying the Route.

M. de Lesseps betook himself to the wilderness, and dwelt there for four years, making observations and borings all along the course of the future Canal. Sixty camels were needed to carry the fresh water, stores, and equipment of the little party. For months at a time they were completely cut off from the outside world, tramping the lonely desert, quietly but painstakingly carrying out their surveys. One of the first things M. de Lesseps ascertained was the fact that the level of the two seas was the same, and that there would be no danger of an inundation. A sojourn of a whole year on the shores of Lake Menzaleh satisfied him that a secure harbour could be constructed there. Patient watching and repeated scientific experiments proved that the sand of the desert did not accumulate, as was commonly believed; and borings made at nineteen separate points between the Red Sea and the Mediterranean showed the soil of the isthmus to be firm and fixed, and therefore not liable to become slimy, as the opponents to the undertaking had predicted. In short, M. de Lesseps, in the course of this preliminary investigation, reached two conclusions, afterwards confirmed by the celebrated British engineer, Sir John Hawkshaw, C.E.—namely, (1) that no insurmountable engineering difficulties would be met in the construction of the Canal; and (2), that no obstacles of an insurmountable character would prevent the constructed Canal being kept open for navigation.



MAP OF THE SUEZ CANAL.

The Lakes.

In the isthmus there are a number of lakes, and M. de Lesseps boldly decided to run his Canal through them or into them—a plan which was finally followed, as will be seen in the map showing the course of the channel. Before the Canal was cut, however, many of them were virtually dried-up depressions, which have now become lakes of considerable areas. In all, the Canal passes through five—Lake Menzaleh, Lake Ballah, Lake Timsah, and the Great and Small Bitter Lakes. The Canal track in these lakes has an aggregate length of 27 miles. Excavations were required, however, through Lakes Ballah and Timsah and the Small Bitter Lake, as well as along a portion of the Great Bitter Lake. The distances from Port Said to these lakes are as follows:—

	Nautical miles.
Port Said to north end of Lake Ballah	26
Port Said to south end of Lake Ballah	30
Port Said to north end of Lake Timsah	41
Port Said to south end of Lake Timsah	44
Port Said to north end of Bitter Lakes	53
Port Said to south end of Bitter Lakes	73

The total distance from Port Said to Port Thewfik is 88 nautical miles (100 English miles), or 160 kilometres. Port Thewfik is the Red Sea terminus and adjoins Suez.

Opposition to the Scheme.

Having drawn up his plans, M. de Lesseps went to Constantinople and laid them before the Porte, who sanctioned the scheme, subject to the approval of the European Powers. This action apparently annoyed the officials at Cairo, and in Great Britain

much hostility was shown towards the enterprise. Lord Palmerston denounced it as "one of those bubble schemes which are often set on foot to induce English capitalists to embark their money upon enterprises which in the end will only leave them poorer, whomever else they may make richer." The great engineer, Mr. Robert Stephenson, while not condemning its practicability, cast doubts upon the commercial prospects of the project. The blow came when Egypt refused her consent. De Lesseps retired to his farm in France, and for some years the matter was entirely dropped.

In his biography, M. de Lesseps relates how one day, while on the roof of a house he was building, in the midst of scaffolding and carpenters, he received a newspaper which announced the death of the Khedive and the succession of Mohammed Saïd, to whom he was well known.

The Khedive grants Permission.

Without delay M. de Lesseps took steamer to Egypt, and at a favourable opportunity laid the matter before the new Khedive. The latter was in his tent surrounded by his ministers. He asked the engineer to draw up a written statement setting forth the scheme, and to let him have it as soon as possible. Jumping on to his horse, M. de Lesseps hastened to his own tent, and soon had returned with the desired plan—contained in less than a page and a half of foolscap paper—setting forth the whole question briefly, but clearly and distinctly. The Khedive read it to the assembled ministers, accompanying it with a translation in Turkish, and asked their advice. They replied that the proposal of their guest, whose friendship for the Khedive and his family was known, could only be welcomed.

Thus in the desert—for this incident occurred far from Cairo—was the permission to build the Canal granted. On his return to the capital the Khedive remarked to the Consul-General of America, when discussing the subject, "I shall clean the pan against you Americans. The Isthmus of Suez will be pierced before yours!"

An International Consultative Commission, selected from among the most celebrated hydraulic engineers of Europe, was appointed to report on the scheme. Their final report was adopted and signed by the Khedive in June 1856. It virtually accepted the plan originally proposed by M. de Lesseps, only here and there making quite minor alterations. The French engineer estimated that the cost of excavating the Canal would be £8,000,000, and a company was formed in Paris soliciting subscriptions to this amount. Up to this time the only Powers that officially recognized the scheme were Turkey, Russia, France, and Austria. The British Government absolutely ignored it. With a view to interesting the British public and British capitalists in the project, M. de Lesseps visited England and interviewed the authorities of many of the principal towns, explaining the leading features of his scheme, and pointing out the advantages which British commerce was certain to derive from its accomplishment. His efforts were certainly not crowned with success; most of the money was supplied by France. Curiously enough, much of it came from the poorer classes, and some of these earlier shareholders made quite a fortune out of their speculations.

British Apathy.

On April 25, 1859, M. de Lesseps turned the first spadeful of sand at Port Said. At this port to-day they will sell you supposed photographs of the ceremony, in which the figure of the great engineer is conspicuous. It was not long before the promoters of the scheme recognized the magnitude of their task, and the innumerable difficulties they would have to surmount. Armies of workmen had to be transported to the scene of operations, housed in tents, and provided with fresh water and provisions, which had

The Work begun.

to be brought on the back of camels from places so distant as Cairo and Alexandria.

At the end of two years not a fiftieth part of the Canal proper had been cut, and it became evident that more money would be needed. The original capital of £8,000,000 was consequently increased to £17,120,000, thanks to the Emperor Napoleon's award of £3,800,000 and to subsequent loans amounting to £5,320,000. It was found necessary to reduce the width of the waterway to 76 feet at the bottom—less than one-half of the width recommended by the Commission. As compensation for this reduction in width, it was decided to construct "gares," or sidings, at frequent intervals, to allow vessels to bring-up for the purpose of passing each other or to moor fo the night.

Building Port Said.

Before much excavation work could be carried out along the route of the proposed Canal the engineers had practically to build Port Said. No materials could be collected nor workshops erected here until a channel had been dug through the bare sand, and docks constructed in which large ships could enter with their cargoes of stores. It was further necessary to build a vast breakwater, for the twofold purpose of keeping the mud out of the Canal, and enabling vessels to approach the mouth of the Canal with safety even in rough weather. This breakwater is one of the striking features of the port. The western pier runs out to a distance of more than a mile, and is 1,500 yards distant from the eastern pier—an arc about 1,100 yards in length. Stones, which had to be transported great distances, were used at first, being simply dumped on to the site from lighters. Later on, after the work on the Canal had progressed somewhat, the engineers finished off these piers or jetties by building up from the consolidated stone foundation massive concrete walls, composed of blocks weighing 20 tons apiece, cast in moulds, and laid in place by giant cranes.

From Port Said the Canal crosses about 20 miles of Lake Menzaleh, in which it is over 300 feet wide at the surface. Twenty-two miles farther on it reaches Lake Timsah by means of a cut dug through the ground to a depth varying from 30 to 80 feet. Lake Timsah itself is 3 miles long, and at this point the flourishing town of Ismailia, where many of the employees of the Company reside, has taken the place of a former small Arab village. To Lake Timsah a fresh-water canal was made from the Nile, to upply the population engaged on the line of the maritime Canal. When this canal was completed a great saving of expense was effected, as the cost of bringing fresh water from the Nile for the workmen had been very excessive.

The work from Lake Timsah to the edge of the Bitter Lakes was very heavy. Deep cuttings, varying from 30 to 62 feet, were necessary. The deepest cutting of all was at El Gir, where the excavation, when originally completed, was 172 yards wide at the summit-level, 112 yards wide at the water-level, and 85 feet deep. Embanking rather than excavating was the kind of work required in passing through the Bitter Lakes, the surface of that region being very little above the intended level of the great Canal. From the Bitter Lakes to Suez, a distance of about 13 miles, the work again became severe, ground to the depth of from 30 to 56 feet having to be dug out and carted away.

Sudden Withdrawal of Labourers.

Briefly, cuttings had to be made for 66 miles of the course, while 14 miles of the bed were dredged through the lakes, leaving but 8 miles requiring no works of any kind. The Khedive supplied an army of fellaheen, 30,000 strong, for the heavier and more laborious parts of the work. After they had been engaged for some time they were suddenly withdrawn by in-

ARAB SAILING-BOATS PASSING A DREDGER IN THE CANAL NEAR KANTARA.

structions of the authorities at Cairo. These men were forced labourers. They had been sent to work on the Canal by the orders of the Khedive, much against their own wishes. It looked as if this sudden withdrawal of labour would wreck the whole scheme. The engineers, however, were equal to the emergency. They hired as many fellahs as they could, and superseded manual labour to a large extent by ordering powerful dredging machines and elevators of colossal dimensions. The larger machines cost £20,000 apiece, and were rightly regarded at the time of their construction as marvels of engineering skill.

Huge Dredgers.

The elevator was a contrivance for lifting the box of sand from the dredger and carrying it on to the embankment. One end of the elevator hung over the punt or barge in which the boxes of dredgings were landed; each box was drawn up by a steel rope and carried on a small truck to the other end of the elevator, which extended several yards over the embankment. On reaching that point, the end-door of the box opened, the contents emptied themselves over the ground beneath, and the empty box then ran down the return line of wire rope back to the punt.

A far more effective machine, however, was the dredger with floating conduit attachment, called by the French a *couloir*. This apparatus consisted of a long mechanical duct, with a slightly inclined channel 5 feet wide and 2 feet deep, one end connected with the dredger and the other running out desertwards over the embankment. It was supported in the middle by an iron framework on the deck of a barge. A steam-pump kept a stream of water flowing through this channel, so that when the dredged-up material fell into the upper end of the *couloir*, it easily ran through the duct and was cast ashore on the bank,

thus saving all the labour of filling the spoil into boxes and removing it to the bank by means of an elevator. The action of the *couloir* was sometimes aided by a *balayeur*—that is, an endless chain passing through the channel, and bearing with it a number of iron scrapers for removing accumulations of slime and mud. Some idea of the enormous size of these machines may be gained when it is stated that the largest of them were seventy-five yards long; if placed on end, one of them would have towered nearly eight yards above the London Monument. To facilitate the rapid removal of the excavated dirt, sand, and mud, tracks were laid on either side of the route. The dirt was either dumped down into the open trucks, or shovelled into them by the labourers and carted away. Horses, mules, camels, and small steam engines were used to transport the trucks into the open country. The quantity of material removed by these gigantic excavators was 2,763,000 cubic yards a month. In all, 80,000,000 cubic yards of sand, earth, and rock were excavated before the Canal was completed.

The Balayeur.

The last barrier was pierced on August 15, 1869, almost exactly ten years from the date

P. AND O. BOAT PASSING THROUGH THE CANAL.

Notice the fresh-water canal alongside, and the shrubs planted to check the sand.

A LONG-SHOOT DREDGER TIED UP IN GARE TO ALLOW A SHIP TO PASS.

(By courtesy of the Suez Canal Company.)

The Canal completed.

of commencing the work, and on November 17 following the Canal was opened for traffic. As M. de Lesseps declared at the time, the project had demanded of him five years of study and meditation in his closet, four years of investigation on the spot, and eleven years of patient toil. On December 31, forty-four days after the opening of the Canal, when in several places the depth was less than 20 feet over a width of 60 feet, the Company issued the following statement as to the cost of the undertaking :—

General expenses of the constitution, cost of negotiations, commission, stamps, and expenses as to shares..................	£561,380
Cost of management for eleven years........	567,300
Interest, dredging construction, including sinking fund..........................	3,316,520
Service of health, telegraph, and transit...	533,538
Cost of construction	11,654,223
	£16,632,961

The cost thus exceeded more than twice the original estimate.

M. de Lesseps was sufficiently sanguine to estimate that the tonnage of the ships passing through the Canal would be three millions in the first year, and probably twice as much during the second year. How far his expectations exceeded the actual results may be gauged from the following table of the number of ships and their tonnage that passed through the waterway during the first three years of its existence :—

Year.	No. of Vessels.	Gross Tonnage.
1870	491	436,618
1871	761	761,875
1872	1,082	1,439,166

It was not until 1877 that the tonnage of the vessels reached the 3,000,000 mark.

A HUGE BUCKET DREDGER.

(Messrs. Lobnitz and Company, Limited, Renfrew.)

Need for Improvements.

In 1883 there was a universal admission that a radical improvement in the management of the Canal was needed if the scheme was to be a success. This was brought about by the Company suddenly increasing the toll on the steamers using the Canal, and by the startling augmentation in the traffic due to the adoption of iron steamers on the Red Sea

HUGE STONES RAISED BY THE BUCKETS OF A DREDGER BUILT BY MESSRS. FLEMING AND FERGUSON OF PAISLEY.

This photograph gives a good idea of the work of which the modern Dredger is capable.

route to the Far East. The upshot of the discussion was that a Commission was appointed, consisting of eight Frenchmen, eight Englishmen, and six members of other nationalities. They had two alternative schemes to consider — whether the Canal should be enlarged and deepened, or whether a second canal should be made parallel to the first. The first plan was adopted after lengthy discussions, and the work put in hand. By 1889 the Canal had had its bottom width increased from 72 feet to 121 feet 4 inches, and its depth from 26 feet 3 inches to 27 feet 10 inches.

In 1885 a still further improvement was carried into effect—namely, the lighting of the Canal by electricity, so that ships might make a safe passage of the waterway by night. A system of leading marks, supplemented by Pintsch lightbuoys, was therefore established along the banks of the Canal to mark the channel. It was soon discovered, however, that this device was insufficient to ensure perfect safety, and the difficulty was surmounted by making the vessels illuminate their own course. By the rules of the Company each vessel must carry four lights, to one of which should be supplied a powerful reflector, capable of casting a light 4,000 feet ahead of the vessel. The Mangin reflector is generally used. Of the other three lights, one should be placed astern and one on each side of the ship. Men-of-war and the large mail steamers carry their own apparatus. Smaller vessels generally use a portable apparatus, which they hire on entering the waterway and return on leaving it. The first vessel that effected a free passage by night was the P. and O. steamer *Carthage* in 1886, the time of transit being eighteen hours. Before the lighting of the Canal, steamers often took twenty-eight hours and more to traverse the 100 miles of artificial waterway.

Electric Lighting of the Canal.

During the last few years, particularly at the Mediterranean end of the Canal, thousands of trees and shrubs have been planted along the banks. This has been done in order to protect the shores and approaches. Along the water's edge a reed of unusual size, the *Arundo gigantea*, which spreads its roots rapidly into the mud and quickly attains a height of from ten to twenty feet, has been established. This vegetation has been found to retard erosion greatly, and to break the swells caused by the passage of ships. Farther back on the slopes of the banks have been set, with success, several varieties of tamarisks, whose branches take root when the sand-hills just cover them, and which are intermingled with herbaceous plants like the orach and the alfa. Then farther back still, at a distance of about 350 feet from the water's edge, are hedges, 170 feet long, formed of arborescent plants, to prevent the encroachment of the

Bank Protection.

desert sands driven up by the wind. It has been found that Bengal fir trees, poplars, mulberry trees, and even the sycamore generally flourish well on these plantations, thanks to artificial irrigation obtained by cutting ditches from the fresh-water canals leading from the Nile and running parallel for many miles to the maritime Canal for the use of the inhabitants.

By 1900 the tonnage of vessels passing through the Canal had increased to 9,738,152 tons, and it was clear that further widening and improvement were necessary. In the following year an appropriation of £1,000,000 was granted for this purpose. The scheme has been pushed forward during the last five years with great activity, and it is anticipated that it will be completed by the end of 1913. The Canal will then have a section double the original size.

Widening Operations.

It would be tedious to give a detailed description of the work now going on at this great waterway. Suffice it to say that, quite apart from the widening scheme, a whole fleet of dredgers is continually engaged on merely keeping the channel free from sand. We get some idea of the magnitude of this task from the following figures, which represent the amount of material excavated from the Canal itself during the years 1904–6 :—

1904..................	1,353,497 cubic yards.
1905..................	1,760,864 „ „
1906..................	1,918,595 „ „

In addition to this, the dredging necessary at Port Said aggregated during the same period 1,933,348, 1,842,722, and 1,464,935 cubic yards respectively.

WIDENING THE CANAL. *(By courtesy of the Suez Canal Company.)*

More interesting still is the actual work connected with the widening scheme. For this, the amount of excavation carried out in 1904 totalled 1,689,275 cubic yards of earthwork, and 1,863,646 cubic yards of dredging. The following year saw the removal of 1,570,476 cubic yards of earthwork and 914,316 cubic yards of dredging; while, in 1906, 3,255,271 cubic yards were dredged, and some 1,829,564 cubic yards of earth removed. The ballast above the water-level is removed by manual labour, terraces being cut into the banks, along which temporary railway tracks are laid. From the water-level to the prescribed depth dredgers of various types are employed, some cutting their way into the bank and dumping the excavated material, by means of overhead transporters, upon the bank, and others discharging it into lighters. The ballast consists, for the most part, of sand, the rock encountered being approximately four per cent. of the total amount. In the dredging of the navigation channel itself the type of dredger with floating conduit is most favoured, the excavated material being discharged through the pipe, usually where the bank is so low that its height may be increased to advantage.

To accomplish this work the Company employ the largest and finest dredgers in the world. The newer ones are capable of dredging to a depth of 36 feet. One of their most remarkable dredging machines is the *Dérocheuse*, which is able to remove even rock. It was built by Messrs. Lobnitz and Company of Renfrew, and is fitted with rock-breaking rams. These rams, which are in principle simply huge chisel-pointed hammers, weighing four tons each, are raised by hydraulic power and allowed to fall through from 10 to 20 feet. There are five on each side of the well, and an ordinary bucket-dredge, working between them, raises the rock broken by the hammers. Among the Company's extensive plant are a 60-ton floating sheerlegs and a 12-ton floating crane. For the purpose of docking their vessels quickly they have at Port Said a 3,000-ton floating dock.

A Rock-breaking Dredger.

A glance at the following table shows the improvement which has already been effected in the waterway since it was first declared open :—

	Depth.	Width at Bottom.	Width at Water-level.
When opened......	26 ft.	72 ft.	150 to 300 ft.
At the present time	34½ ft.	147 ft.	240 to 360 ft.

As a matter of fact, when the Canal was opened the depth of 26 feet aimed at was not attained for the whole length of the channel. In some places it did not exceed 20 feet, nor the width at bottom 60 feet.

At short intervals "gares," or sidings, where vessels proceeding in opposite directions are able to pass each other, have been cut. Twelve were completed in 1904, and plans were then prepared for the construction of twenty-one others, principally near the lakes. Each of these gares will have a length of 2,460 feet, and approaches at either end of 984 feet. At a gare the width at bottom of the Canal is 180 feet, and at water-level over 300 feet, the width of the gare itself being 93 feet.

"Gares," or Sidings.

One of the greatest dangers with which the authorities have to contend is the stranding or foundering of vessels, whereby the passage through the Canal is blocked. In the year 1905 such accidents averaged 1·7 per cent. of vessels passing through, whereas in 1885 the average was 4·3 per cent. This improvement is attributable to the widening of the waterway, and to the improved facilities now in vogue for enabling vessels to proceed. In 1905, however, the resources of the authorities were severely taxed by the foundering of the steamer *Chatham* through collision with another vessel. The ship sank in the centre of the channel, tying

Stranded or Sunken Vessels.

BLOWING UP THE WRECKAGE OF THE "CHATHAM," NOVEMBER 22, 1905.
The explosion created a hole 73 feet deep in the Canal bed.
(*By courtesy of the Suez Canal Company.*)

up all navigation for several days. Within a period of four days the Company had to handle no less than 109 vessels which had been delayed, 53 passing from the north and 56 from the south without the slightest hitch directly the channel was reopened. The wreck itself was removed by being blown up, and the débris was salvaged.

Blasting a Wreck.

It was a dangerous piece of work, as the *Chatham* had on board about 100 tons of dynamite as well as a supply of detonators. The blasting of the ship was accomplished by means of large mines, each containing 300 lbs. of explosives, and fitted with electric fuses. One of the mines was placed by divers in the hold in which the cases of dynamite had been loaded, and the other was lowered into the hold containing the detonators. Cables were laid from the mines to the shore, where they were connected to two of the telephone wires on the banks of the Canal. The firing-station was located three miles from the sunken wreck, and after the circuits had been tested the mines were fired. An enormous column of water and débris immediately arose, and ascended continuously for five seconds, the estimated height of the column being over 1,500 feet. The explosion was heard ten miles away, the water of the Canal overflowed the surrounding country for 1,000 yards in every direction, and fragments of the ship were distributed over a circle 1,200 yards in diameter. The enormous downward thrust of the explosion was revealed by soundings taken over the spot

THE BOILERS, ETC., OF THE "CHATHAM," SHOWING THE EFFECTS OF THE EXPLOSION.
(*By courtesy of the Suez Canal Company.*)

where the ship had lain. Here was found a huge hole over 73 feet in depth. This is the greatest explosion of dynamite ever recorded.

The "Block" System.

A fine system for giving speed to all ships in transit is in operation, much resembling the well-known railway "block" system. The Company controls the departure and entrance of all ships, the order of precedence being wholly in their hands. No ship may demand immediate passage for any reason, but preference is given to regular mail steamers under Government control. These carry blue signals and a white light at night. The Canal is blocked out in divisions, and at the head office in Ismailia a dummy model shows the exact moving position of every ship in the Canal. No vessel may proceed until the way is clear. A complete system of telegraphic signals ensures this condition being observed. Dotted along the banks at regular intervals are small stations, each furnished with a high masthead, from which red and yellow balls by day and coloured lights by night announce to each vessel whether to proceed through the next division or to "tie-up" and wait for one to go by from the opposite direction. Ships going the same way are not allowed to pass each other. Vessels of small tonnage may pass when travelling in opposite directions, or a large steamer may pass a small one, the latter drawing into the bank while the bigger one goes by.

Rules governing the Traffic.

The rules governing the passage of vessels is certainly strict. Written information as to his ship must be handed in by each captain—her name, nationality, draught, and port of sailing and destination, as well as his own name and that of owners and charterers, number of passengers and crew. Naturally, nothing must be thrown overboard, especially ashes and cinders; also, nothing is to be picked up, notice of any article lost overboard being given at the nearest station. No guns shall be fired and no steam-whistles blown except in cases of extreme danger. One rule also states that burial in the Canal banks is strictly forbidden. All sailing vessels above 50 tons must be towed; if above 100 tons, they must take a pilot; and no sailing craft may navigate at night. Though pilots are compulsory, the entire responsibility remains with the captain. If a collision appears inevitable, all ships are instructed to run aground to avoid it, the sandy and yielding nature of the shallows near the banks offering the less of two evils; but no floating ship is permitted to help off a grounded one.

ONE OF THE SHEERLEGS USED FOR REMOVING WRECKAGE FROM THE WATERWAY. WORKING LOAD, 60 TONS.

(By Courtesy of the Suez Canal Company.)

We cannot do better than describe a passage through the Canal to show the efficiency of its working. It was dark when we entered the channel at Port Said. Along the banks we discerned, in the bright moonlight, the trees and

A SUCTION DREDGER AT WORK "MAKING GROUND" BY DEPOSITING SAND INSIDE A WALL.

(By courtesy of the Suez Canal Company.)

shrubs which have been planted to protect the Canal shores. The croakings of frogs were the only sounds that broke the silence of the desert. On the eastern bank distances are marked in miles, on the western bank in kilometres. In the lakes the deep channel was indicated by white buoys on the east and by red buoys on the west. At night, of course, these are illuminated. Before we had proceeded very far, signals (two red lights above a yellow) informed us that it was our turn to wait the passing of a mail steamer from Suez. Immediately our speed slackened as we approached the mooring-posts. A small boat must always be in readiness for use with each steamer, and, manned by two or three agile Arabs, a dark object shot out from our side, while shadowy forms jumped ashore, making fast, by bow and stern hawsers, to the deeply-embedded bollards on the western bank. At once all our lights were extinguished—the signal that we were fast—and the approaching steamer drew near majestically, her searchlight projecting a brilliant light ahead as she glided on. The welcome signal to proceed—a red light above a yellow—finally flashed forth for us from the station; the Arabs deftly uncoiled hawsers, cast off, and jumping into their small boat were alongside and aboard in an instant. Our lights once more shone out, and we proceeded on our quiet way.

Passing through the Canal.

Ismailia, on Lake Timsah, was perhaps the most interesting place passed on the whole route. This is the central point of the Canal, and is a thriving town. The homes of the pilots are situated here; it boasts restaurants, shops, cafés, a theatre, and a

CONSTRUCTING A CANAL WALL.

(By courtesy of the Suez Canal Company.)

central railway station. The remainder of the trip was of little interest, but as the sun rose we detected small caravans of camels making their way along the principal highways laden with merchandise. The trip occupied exactly sixteen hours.

Further Improvements.

Since 1896, £1,250,000 has been expended upon the widening and improvement of this great waterway. More than twenty stations have been provided at various points between the termini, nearly all the curves have been eased, and gares provided at intervals of about 3 miles. During the same period vast improvements have been effected concerning the welfare of the numerous employees engaged in the maintenance of the Canal. The ravages of the mosquito-bred fever which formerly prevailed along the isthmus have been checked. A modern sanitary system was evolved for Ismailia by the Egyptian Government in co-operation with the Canal Company, the results of which have been completely successful. At Ismailia stands a huge hospital, with its dispensaries, where the sick of the surrounding country receive free medical assistance and advice. A comprehensive idea of the natives' estimation of this interest in their well-being is afforded by the fact that the dispensers of Ismailia and Port Thewfik, the Red Sea entrance to the Canal, have attended 120,000 cases and held over 500,000 consultations.

Apart from the actual widening of the Canal, the improvements include many interesting enterprises. At Port Said, to the west of the railway station, a new dock is to be constructed. The object of this is to encourage the building of warehouses, so that vessels may berth beside the piers, thus obviating the necessity for discharging into lighters and barges as at present. Should this first dock prove successful, a second and a third will be made upon similar lines, and connected by a navigable channel with the Canal proper. The opening of the Egyptian Government railway, which links Port Said with Cairo, has resulted in a heavy traffic, vessels stopping at Port Said to unload their cargoes intended for Egypt. Also, a number of basins and docks for colliers and oil-boats are in course of construction upon the eastern bank. When these are completed, the space at present occupied by this class of traffic will be available for vessels carrying general merchandise destined for the interior of Egypt. On the African bank of the Canal facilities are to be provided for the unloading of colliers and other vessels, and for the erection of depôts along the line of the railway. The gare at Port Thewfik is to be deepened, and other improvements effected. Furthermore, a large tract of land has been reclaimed from Lake Menzaleh. A deep and wide channel has been dredged across the shallow waters of this lake, and a ferry service established by the Menzaleh Canal and Navigation Companies between Port Said and Matarieh, the eastern point of the fertile country of Mansourah. This channel is to be connected ultimately to the main waterway by means of a lock, the present fresh-water canal extending alongside the main Canal being siphoned under the channel.

Some conception of the enormous traffic handled by the Canal Company may be gained from the following figures, which give the number of vessels, their tonnage, and the tolls paid, since 1902 :—

Year.	No. of Vessels.	Gross Tonnage.	Gross Receipts.
1902	3,708	11,248,413	£4,209,381
1903	3,761	11,907,288	4,205,934
1904	4,237	13,401,835	4,715,706
1905	4,116	13,134,105	4,609,370
1906	3,975	13,445,504	4,320,742
1907	4,267	14,728,434	4,700,137

Of the 4,267 ships which used the Canal in 1907, 2,651 flew the British flag, 580 the German, and 239 the French. The total number of passengers carried by the ships in this year through the waterway was 243,826.

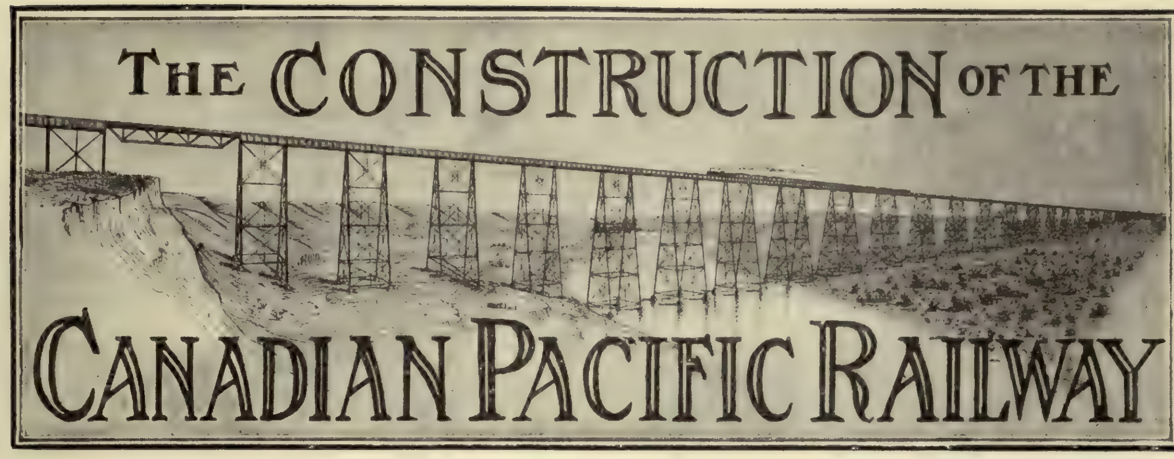
Financial Position of the Company.

Coincident with the remarkable progress in the traffic receipts and high dividends that prevail, the dues have been reduced. Originally the tariff for all laden vessels stood at 8s. per ton; in the 'eighties it was reduced to 7s., and at a later date to the existing levy of 6s. per ton. The tariff for passenger vessels has always remained the same—8s. per ton. The reserve funds of the Company to-day stand at £1,000,000. A special fund provides for the acquisition of new machinery to maintain and improve the Canal. By the purchase in 1875, for £3,976,582, of the 176,602 £20 original shares held by the Khedive, the British Government obtained joint control over the Canal with France. Twelve years later a convention was signed at Paris which placed the Canal under a joint Commission, and guaranteed its neutrality and a free passage for ships in time of war.

THE LESSEPS MONUMENT, PORT SAID.

A SNOW-SHED ON THE CANADIAN PACIFIC RAILWAY.

THE CONSTRUCTION OF THE CANADIAN PACIFIC RAILWAY



BY J. M. GIBBON

(Of the Canadian Pacific Railway Company) and

STEPHEN PARDOE

(One of the Men who helped to lay the Track).

THE Canadian Pacific Railway is one of the most important railway systems of the world. It owes its existence to the need for easy communication between a prosperous but isolated province on the Pacific shore and the older civilization of the eastern side of the continent. Between these two stretched, for many hundreds of miles, the rolling and almost uninhabited prairies of Manitoba, Assiniboia, and Alberta, and wide belts of extremely mountainous and almost impenetrable country. Previous to the opening of the Canadian Pacific Railway a journey across Canada was a very serious undertaking.

The Origin of the C.P.R.

In 1871 British Columbia entered the federation of Canadian states—on conditions, one being that a railway should be built across the continent to give her access to the Atlantic Ocean. The demand for an iron track nearly 3,000 miles long, from Vancouver city on the Strait of Georgia to Montreal, at first staggered the Government, which, in the then half-developed state of the Dominion, could alone command the necessary resources. The country to be traversed included the difficult rocky districts on the north shore of Lake Superior; 900 miles of prairies rising gradually westwards; and the vast ranges of the Rockies and the Selkirks, and the Gold Range of Mountains—vast billows of rock which were as little known then as the Central Asian ranges are to-day. The scant population promised great difficulties in the matter of labour and supplies; while the Canadian winter, with its storms of dry, powdery, drifting snow, threatened physical obstacles even more formidable.

Difficulties to be faced.

However, the Government thought the matter over, and decided that what British Columbia had asked for herself would be good for the Federation at large. The Premier, Sir John Macdonald, a man of great persuasive

Note.—*The drawing at head of page represents the Lethbridge Viaduct, C.P.R., now building. Height, 300 feet; length, 5,327 feet. Taking both height and length into consideration, this is the largest bridge in the world.*

powers and iron determination, said that the year 1881 should see the line completed.

A Slow Start.

Unfortunately, he had not reckoned with, or at any rate had under-estimated, the political element underlying so truly national an enterprise. Though actual surveying began in 1871, and was pushed ahead with the utmost vigour, construction was grievously hampered by a lack of continuity of policy. The Conservatives, when in power, sought assistance from private persons; and when the Liberals got their turn, they went solidly against the employment of any but Government officials. As a consequence, four years were practically frittered away, and the work done in that period totalled only a small amount of grading at the eastern end. By 1879 just 700 miles of track had been laid. British Columbia became excited, and reminded the Government of their promise. The Government—now Conservative once more—fixed things up with "B.C."

Public Tenders called for.

and called for tenders for the completion of the line. A syndicate undertook the contract—Messrs. J. J. Hill, R. B. Angus, G. Stephen, Duncan MacIntyre, J. S. Kennedy, Morton Rose, and Cohen and Reinach, the last three providing a large portion of the "sinews of war." The Company into which they formed themselves stipulated that it should receive 25,000,000 dollars in gold, and an equal number of acres of good prairie land; that it should be accommodated with free right-of-way and sites for stations, docks, etc.; that all materials should be admitted untaxed; that the Company's lands should be exempted from taxation; and last, but by no means least, that the Government should make it a present of the 700 miles of partly completed track.

The Government, on its side, exacted the condition that the line should be opened for traffic by May 1891, which meant that more than 250 miles of rail must be laid every year.

As one of the Company's main assets—the land—depended for its value upon the railway, and so could not be realized to any profit until the railway should be built, the Company presently found itself in financial straits. Its stock fell heavily, and a loan of £6,000,000 had to be made from the Government, which took advantage of the position to clip five years off the time originally allowed for construction.

Terms of the Contract.

The engineering history of the C.P.R.—to give it its now familiar designation—opens with the reports sent in by the engineer-in-chief to his Government at Ottawa. The Government engineer, now known as Sir Sandford Fleming, outlines in his reports the broad principles on which construction was to proceed.

"On being called upon to take in charge the work of exploration, the Government deemed it best to leave me entirely untrammelled by any specific instructions. I was simply informed and directed that no effort should be spared to discover, with the least possible delay, a practicable route for the railway, in order that the terms of the union might be carried out.

Surveys made.

"At the commencement of the survey the following leading principles were laid down:—

"1. That every effort should be directed to the discovery of a line through the woodland region, which would prove the shortest and best possible between the existing railway system in the two elder provinces and the province of Manitoba.

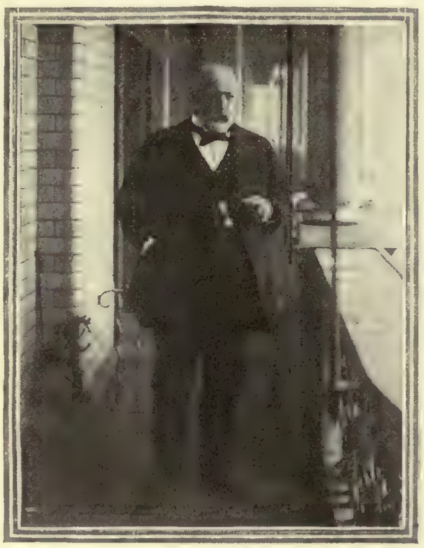
Points to be considered.

"2. That the above line should touch, or by a branch line connect with, Lake Superior, and constitute as nearly as possible the shortest and cheapest route for transport of natural products from the prairie region to the navigable waters of the St. Lawrence.

MAP SHOWING MAIN LINES OF CANADIAN PACIFIC RAILWAY.

"3. That the greatest possible energy should be brought to bear on the work of exploration in the western region, in order to discover with as little delay as possible a practicable line for the railway through the Rocky Mountain zone — a line which would prove the shortest and least expensive, which would best serve the interests of the country, and lead to the most eligible harbour on the Pacific coast.

"4. That the route for the railway through the prairie region, while connecting with the line in the eastern and western sections, so as to reduce the distance between Atlantic and Pacific to a minimum, should be projected to avoid the most formidable river crossings, and approach the rich deposits of coal and iron, at the same time to be conveniently near the large tracts of land available for settlement."



(*Copyright, Illustrations Bureau.*)

SIR WILLIAM VAN HORNE, K.C.M.G.,
Chairman of the Canadian Pacific Railway Company.

Fleming crosses the Mountains.

Early in July 1872 Mr. Fleming—as he was then—started with a small exploratory expedition to cross the continent. He followed the route from Nepigon by the Dawson route to Lake of the Woods, reaching Fort Garry (now Winnipeg) on July 31. Thence by Forts Ellice, Carlton, Pitt, and Victoria to Fort Edmonton, where he arrived on August 27. By September 15 he had reached the Yellowhead Pass. Here he followed the Fraser River, and crossing over to Canoe River, descended the North Thompson River to Kamloops, and so down the Fraser River again to Vancouver Island and Victoria, completing his journey on October 11. One realizes what the existence of the railway means when we recollect that Victoria is now separated from Nepigon, not by three months but by three days.

The line taken by Mr. Fleming on this first trip across the prairies and the Rockies was the route he eventually selected in preference to ten other alternative routes located by the surveys working under his direction farther north. It provided the easiest gradient to Burrard's Inlet, and the expert opinion of the Pacific coast was solidly in favour of the terminus being in that neighbourhood, for both commercial and political reasons. The telegraph was actually completed as far as Edmonton, and it was not until the syndicate of capitalists, headed by George Stephen (now

Lord Mountstephen), took over construction from the Canadian Government that the present route *viâ* Calgary was decided on. Fortunately, until 1881 actual construction was confined to the sections north of Lake Superior, from Fort William to Winnipeg, and from Port Moody on the Pacific coast to Kamloops, so that there was no necessity to scrap any of the work completed, even though a new route over the prairies and the Rockies was ultimately chosen.

Work began in the year 1874. In that year there was a fall in the price of steel rails, and 50,000 tons of rails with the necessary fastenings were bought from English companies, who were allowed to import duty free. Later on Krupps of Essen obtained some large orders.

A Fresh Start made.

It was natural that the first efforts of the Government should be devoted to that portion of the line which was sure to pay—namely, the section from Fort William, at the head of Lake Superior, into Manitoba. In August 1876 the first locomotive was landed at Fort William, and by 1881 the line was open for traffic north of Winnipeg as far as Selkirk. This section presented heavy engineering difficulties, especially as the lowest possible gradients had to be secured to make the line pay. Mr. Fleming's notes provide some interesting comment on this aspect. "The gradients and alignment of a railway have much to do with its capacity for business and the cost of working it; by attention to these features it is quite possible in some cases to double the transporting capacity of a railway, and very largely reduce the cost of carrying freight over it. That portion of the C.P.R. between Red River and the navigable waters of Lake Superior is precisely one of those cases where the utmost attention should be paid to its engineering features."

The Lake Superior Section.

As a matter of fact, from Fort William to Selkirk the gradients were kept under 1 per cent. Only 60 miles out of 410 were over ·5 per cent. So profitable has this section of the line proved to be, and so heavy the traffic, that it has now been double-tracked.

Sandford Fleming was also the engineer of the Intercolonial Railway, and this, one of the best laid railways on the American continent, was set up as the standard for the Canadian Pacific. The gauge of the road is 4 feet $8\frac{1}{2}$ inches, and the original rails laid of 56 lbs. to the yard were replaced by 70 to 80 lb. rails where the traffic demanded. The specifications for contracts were rigorously upheld.

Gauge and Weight of Rails.

Among the working regulations were the following: "The contractor shall not permit, allow, or encourage the sale of any spirituous liquors on or near the line of railway." "No work whatever shall at any time or place be carried on during the Sunday, and the contractor shall take all necessary steps for preventing any foreman or agent from working or employing others on that day."

Camp Regulations.

These regulations were enforced where possible, as it was to the contractors' own interest that their men should keep in good condition. Neither railroad contractors nor their foremen, however, still less the men themselves, were, or are, of the "kid glove" variety of the human species, and in many camps Sunday was considered a better working day than any of the other six. The sub-contractors realized that the completion of one stretch of work meant the earlier commencement of another; and the men found that four or five additional days' pay per month was not to be despised. In the construction of the main line and branches alike, even as late as 1896, Sunday work was—as in mining camps—the almost invariable rule.

The C.P.R. offered the engineers one advan-

tage denied to those who have to build through country already settled. They could plan out the stations, round houses, divisional points, and tool and repair shops on a scientific plan, unhampered by the demands of landlords. The stations were located about sixteen miles apart on level sections, with passing places half-way between every two stations.

Some Advantageous Conditions.

Heavy as was the engineering on the section from Fort William to Fort Garry (Winnipeg), it was easy as compared with that on the section along the north shore of Lake Superior, which cost 12,000,000 dollars for the 200 miles. Here the rocks are granite and flint, with mica schist and black trap, and to blast them 2,100,000 dollars' worth of dynamite was needed.

Heavy Rock Work.

Even before the northern shore of Lake Superior was reached by those working westwards, the engineers had to face serious problems. The country north of Lake Huron was full of "muskegs"—lakes concealed under a thick surface growth of decayed vegetable matter and peat which is thick, but not deep or solid enough to carry a railroad track. These muskegs had to be filled up with vast deposits of timber and muck piling, used in such quantities that the contractors might well think that they had struck the bottomless abyss itself. At a point between Sudbury and Cartier a lake was lowered ten feet in order to find a base for the track. The lake being on the summit of a convenient gradient, a canal was constructed to draw off the water, and the roadway was built along the shore two feet above the lowered surface of the lake.

Filling in Swamps.

C.P.R. STANDARD PASSENGER ENGINE.

Viewed from the lake, the coast-line presented a most forbidding prospect, but the surveyors found a number of interior lakes just inside the coast-line. "The route was laid out, in some cases, on the smaller lakes inland, and in others upon the perpendicular southern faces of the cliffs, while coves were encircled, crags tunnelled, and fissures and canyons crossed by lofty bridges."

In order to keep the gradient at less than 1 per cent., an enormous amount of deep rock cutting and high bridging had to be done on this section. The Pic River was crossed on an iron truss bridge on stone piers at 110 feet above water, and the track at Jackfish Bay winds so much that it takes three miles to advance half a mile as the crow flies. The

High Bridging.

MINK TUNNEL, ON THE LAKE SUPERIOR SHORE.

(Photo, C.P.R. Company.)

bridges, tunnels, and galleries on this stretch alone cost 1,500,000 dollars.

For sixty miles, between Heron Bay and Schreiber, the line is built through and around the abrupt and precipitous shores of Lake Superior, the lake itself coming full into view many times, and creating in the minds of those who wake to their first view of its waters in the early morning the impression, not of a lake, but of an inland sea, which indeed it is.

Right up to Winnipeg the engineers were never really pressed for time, but the situation changed when British Columbia, which had entered the Dominion on condition that the railway should be built within a certain time, protested at the non-fulfilment of the compact, and threatened to withdraw. The Government was, as we have seen, only too glad to hand over the completion of the road to a company, which relieved it of heavy financial obligations, and would not be so much hampered by red tape or political considerations. The new Company was originally given till 1891 to complete the road, but such was the speed accomplished by the new contractors that the junction of east and west was effected by November 1885, a year earlier than the readjusted limit.

The Prairie Section.

The prairie section was constructed by Messrs. Langdon. Shephard, and Company. They completed the track to Calgary on August 18, 1883, the very limit day specified by their contracts. The crossing of the Rockies was engineered by the North American Railway Contracting Company under Mr. James Ross.

Change of Route.

As already mentioned, the Company which took over the railway from the Government decided on an alignment farther south than the Government route over the prairies. One reason for this was to secure a

MOOSE JAW STATION. *(Photo, C.P.R. Company.)*

lighter gradient. Right up to within four miles of the summit of the Rockies the gradient does not exceed 40 feet to the mile. Although one talks of the prairies as flat, they are really rather steppes. The first steppe stretches for 388 miles from Winnipeg to Moose Jaw. Here there is a rise of 275 feet in 7 miles. The second steppe extends 224 miles to the crossing of the Saskatchewan, and is full of ridges and valleys. "Had cuttings been possible," wrote the engineers, "there would have been less difficulty of location and lighter works; but these are not practicable, as it is a matter of great importance to keep the grade in filling (or embankment) to avoid blockade by snow. The dryness of the season in winter pulverizes the snow. It drifts before the wind, and packs so solid that a horse and

Cuttings to be avoided.

ONE TYPE OF C.P.R. SNOW-PLOUGH.

sleigh can pass over it, leaving scarcely any impression. A drift of this very fine snow, six inches deep, during a blizzard will bring to a dead stop the most powerful engine. Such a drift on the line here would have to be dug out."

The whole route had to be explored and located ahead of the graders during the actual working season. In 1882, during a season of 239 working days, locating parties permanently located 840 miles through a hitherto unexplored country, being an average of over three and a half miles a day.

The engineering staff consisted of five divisional engineers, each in charge of 30 miles, divided into 10-mile sections under an assistant engineer, who had a camp consisting of a rodman, axeman, and cook. When his section was finished he was shifted farther west. The supply camps were 20 miles apart. The contractors had their independent supply camps, 25, 50, and 75 miles respectively from railhead. In 1882 there were 4,000 men at work, with 1,700 teams consisting each of a pair of horses and large four-wheeled wagon.

Staff Organization.

As has been stated, Messrs. Langdon, Shephard, and Company were responsible for the whole prairie portion. They in turn sublet the work to numerous smaller contractors, who undertook the construction of greater or less distances according to the strength of their "outfits." The ordinary sub-contractor generally undertook a five-mile stretch at a time, and was not only responsible for its completion, but had to achieve that completion in his proper turn with the others. Thus one outfit, after finishing its "job," would move on 20 or 30 miles to begin a fresh stretch, passing on its way other gangs all hurrying their work so as to be ready to move in their turn. On the grassy prairie the "right-of-way," 99 feet wide, was marked out by little wooden pegs driven with exact care by the surveying gangs who had just passed on. The whole surveyed line was divided into 100-foot stretches, or "stations," as they were, and are, termed. Every 100 feet were put two pegs giving the extreme width of the right-of-way. In the centre, equidistant from each of these, stood a third, and very important, peg, bearing in figures a statement of the

How the Work was subdivided.

Marking out the Route.

MAKING THE DUMP.

built at that point. Then the teams began their monotonous ceaseless circling, first scraping in as much sod as the engineer in charge would allow (a knotty point this, as sod bulks quickly in a dump and settles proportionately), and then covering it neatly and quickly with earth. On the level prairie this work would go with marvellous rapidity, gang moving on past gang till at the end of the day one outfit had perhaps built some two or three miles of dump.

After the scrapers came the trimmers, whose business it was to level carefully the top of the dump ready for the cross-ties.

height of grade, or "fill," necessary at that point. The top of the completed fill or "dump" must be 14 feet wide; so on either side of this centre peg another peg was driven, the distance between the two showing the width necessary at the foot of the fill to ensure the natural earth slope being maintained on each side.

A sub-contractor's outfit consisted of thirty or forty teams and perhaps one hundred men, and was in itself a little army, every member of which, after the first few weeks, became drilled into a very perfect understanding of his duties. Each outfit would be subdivided into two, three, or four gangs of ten teams under the control of foremen. To each gang were allotted five stations, and two teams with their teamsters and a scrape-holder to each station; every gang or two gangs having a special four-horse ploughing team to loosen the earth for the scrapers to move. The first care of the foreman was to replace the centre grade pegs with stout stakes driven firmly into the ground, each being the exact height of the dump to be

Allotment of Work.

Forming the Dump.

"Muskegs," encountered on the prairie sections as well as among the timber, proved very thorns in the sides of those unfortunate sub-contractors whose allotted portions included one or even two. By hook or by crook sufficient dirt had to be scraped, wheeled, or shovelled on to the quaking turf to prevent the horses from breaking through. Then the wheel-scrapers came into play, bearing earth from neighbouring cuttings, or on level ground from "borrowing-pits," and piling it on top of the shaking morass till the whole seemed to find solid bottom. The dump would often be built the correct height during the day only to sink several feet during the succeeding night, and need rebuilding again and again. A good, well-driven team on easy work might place as much as 100 cubic yards in a ten-hour day, sometimes even more, and as the price paid the sub-contractors varied from 10 to 15 cents per yard, measured in the completed dump, a good stretch of easy work from three to five feet in height meant handsome profits.

"Muskegs" give Trouble.

When, however, as in the case of these muskegs, most of the earth disappeared almost immediately, the loss may be easily understood. Many of the men, especially in Manitoba, were settlers who were glad to find remunerative employment for themselves, and, in many cases, for their teams, during the months between seeding time and harvest. Sometimes those who had had experience of similar work undertook small jobs, contracting for short distances of a few stations each from the sub-contractors, who, of course, made a profit on the work they thus sublet.

Remuneration.

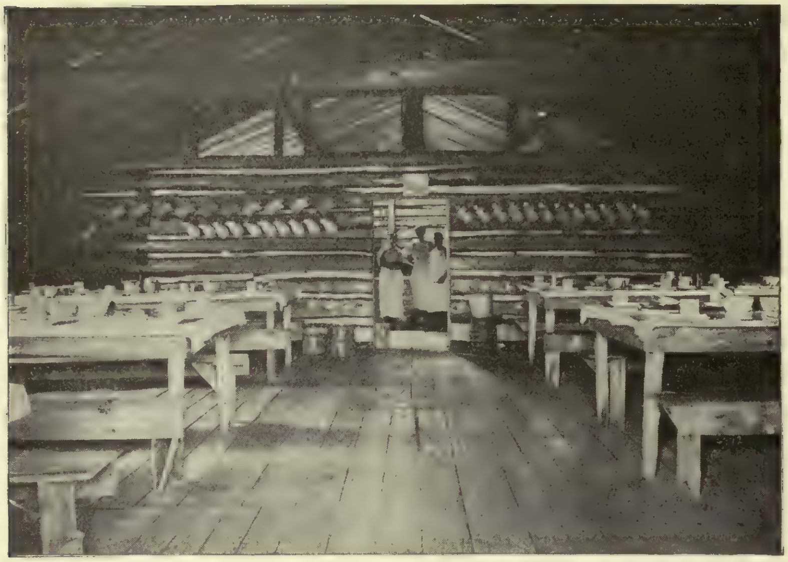
It was naturally impossible to avoid cuttings entirely, as the prairie is in many places not entirely level but rolling. As a precaution against drifting snow, the earth taken from each cut was scraped into a long heap on either side of the cutting, and perhaps 100 feet away from it, so that the snowdrifts might form between the fence thus effected and the cutting itself. Since then these "snow-fences" have in many cases been supplemented with strong board palisades; and now the experiment is being tried of planting rows of trees, which, if they take root and thrive, will undoubtedly do much to remove one of the most expensive items of the winter operation of prairie sections.

Protection against Snow.

The camp of each considerable outfit presented an almost military appearance. One or two large dining-tents, with the cooks' quarters and the office tent, where dwelt the sub-contractor, his book-keeper—who also kept the men's time and ran the store of clothes, tobacco, etc.—and perhaps the foreman, were generally in the centre. All round stood orderly lines of small two-man tents, and at one side the big horse tents and the rows of wagons. The food prepared by the cook and his "cookees" was, though rough, generally good and plentiful. Beef and pork, beans and potatoes, bread and hot biscuits, syrup, tea, and coffee, were the mainstays, heartily consumed three times a day. Early dawn brought the cry of "Roll out, teamsters" from the "corral boss," and by the time the men had shaken themselves out of their blankets the horses—herded during the night by "horse-wranglers"—had been driven in ready to be caught and given their feed of oats and water. Then breakfast, followed by the cry of "Hook up" from the foreman, and the whole force would commence its first five-hour stretch of work. "Unhook" at noon, and dinner; another five hours' work before supper; and then—the blankets, till the morning of a new day. The horses knew as well as the foreman when "unhook" should be called, while each mule was a foreman unto itself in that respect. A minute or two before the expiration of each five-hour period of work one wise old mule would bray, and from that

Scenes in Camp.

A C.P.R. CONSTRUCTION CAMP. *(Photo, C.P.R. Company.)*



READY FOR A MEAL. INTERIOR VIEW OF A CONSTRUCTION CAMP MESS-ROOM.

time until "unhook" the air was hideous with fearful sounds. Stolidly patient, incredibly strong, endued with infinite endurance and devilish vice, no mule would move one second before "hook up" sounded or one second after the correct time for "unhook" to be called had passed. It was a pity that so many good horses succumbed. From one cause and another the mortality among them was very serious. Probably a steady diet of too many oats and too little hay to eat with them, and water often strongly impregnated with alkali to drink, was responsible for the trouble, which may have been aggravated by the bites of the myriads of mosquitoes which infested the whole country during May, June, and July. The mules were tougher. What a mule cannot endure has yet to be discovered. They suffered only from the soft ground or muskegs, where their small hoofs cut through the covering sod and let them in up to their bellies, sometimes indeed over their backs.

Mortality among Horses.

The work across the prairies proceeded rapidly until the coming of winter snows and frosts drove the sub-contractors to winter quarters, some to store their outfits in the growing town of Winnipeg or the American twin cities of St. Paul and Minneapolis, others to the woods to make ties and bridge timber till the return of spring thawed the ground again.

Movable Hotels.

In places the track was laid so rapidly that there was not time to set up camps. Large two-story boarding cars were built for the use of the men. In the upper story the men slept, and in the lower they had their mess. Each car held sleeping accommodation for eighty men. These cars, together with the cooking, inspector's, and workshop cars, were permanent portions of the construction train, and were always left at the front. The rest of the train consisted of twenty-one flat cars (or trucks), and was backed up by the engine, which never had to go more than eight miles for supplies. The sleepers or ties (laid 2,640 to a mile) were packed thirty-three to a car, and the rails (which were 30 feet long) were thirty pairs to a car, together with five boxes of spikes, sixty pairs of fish-plates, and

Laying the Track.

CARRYING SUPPLIES INTO CAMP.

one box of bolts. The sleepers were loaded on to carts and taken ahead on the dump, distributed, spaced, and lined well ahead of the track-layers. In order to unload the rails the train was backed up to the end of the track, and the rails then thrown off the cars, fifteen pairs on each side. The engine then drew off, and the fifteen pairs were loaded on to a trolley drawn by horses, together with the necessary fish-plates, bolts, and spikes. When the trolley reached the last laid rail, a pair of rails was dropped, gauged, and the trolley run forward over them. A gang followed to affix the fish-plates, and was in turn succeeded by the spikers. When the load was finished, the trolley was thrown off the rails to make place for another.

The speed with which the work was done is admirably illustrated in the building of the stations. "The station buildings were erected by a series of gangs of workmen following each other. The first gang put up the framing, joisting, and rafters, etc.; the second put on the sheeting, flooring, and roofing; and they were followed by the plasterers, joiners, and painters. As each gang finished its particular class of work it moved westward, by which arrangement four or five stations were being built at the same time, and each gang got through its own division of labour in time to allow the next one to come on. There were no delays or hitches in the work. The station-house gangs began work 125 miles behind the track-layers, and caught them up at the end of the season."

Quick Station Building.

SECTION GANG BALLASTING TRACK ON A PRAIRIE DIVISION. *(Photo, H. E. Brittain.)*

The headquarters of the constructional department were never more than 100 miles

behind construction. These headquarters were situated at a material yard, where all materials and supplies were assorted and forwarded in train lots of accurately adjusted sets of rails, ties, fastenings, telegraph material, etc. When the track was 100 miles ahead, headquarters (which consisted of portable houses) were transferred in a day to the new point.

The figures given by Sir William Van Horne as to the three seasons' work west of Winnipeg are as follows :—

1881	165·50 miles.
1882..........................	419·86 „
1883..........................	376·78 „

The same authority adds : "It must not be supposed that because the work was so quickly done it must have been poorly done, or that the track was merely stretched out on the surface of the ground. On the contrary, the entire line is thoroughly well built of the best materials, and everything has been done to make it a first-class railway in every respect, and with a view to the greatest economy in working. The transportation department was charged with the delivery of all the materials and supplies at the end of the track ; and when the quantity of these and the great distances they had to be transported are considered, it will be thought no small feat to have moved them

Fast but Thorough Work.

A STEAM-SHOVEL AT WORK. EMPTYING THE SCOOP.

to the front day after day and month after month with such regularity that the greatest delay experienced by the track-layers during two seasons' work was less than three hours."

In fifteen months' time, notwithstanding a winter's interruption, Messrs. Langdon, Shephard, and Company laid 677 miles of main track and 48 miles of sidings, and moved about 10,000,000 cubic yards of earthwork—"a feat," as Van Horne says, "unequalled in the history of railway construction."

Some idea of the rapidity with which the last part of the prairie section was located and

A ROCK CUTTING.

built may be gathered from a story told by Mr. James Ross, general manager of the North American Railway Contracting Company: "Two locating parties were sent to change the line between the river Saskatchewan and Calgary for a distance of 1,181 miles; one party went ahead to determine the practicability of the route for the grade of 40 feet to the mile, and the second party to locate the permanent line. Though these two parties started from a point 74 miles west from the end of track, had three weeks' start of the graders, and were able to locate 4 to 5 miles a day, yet the graders were many times in sight of their back picket man."

In the Rockies.

In 1883, while the prairie section was being completed up to Calgary, the line was being pushed forward from Calgary up the Bow River Pass. Some of the locating parties had to travel more than five hundred miles by cart or pack-horse to the scene of their operations. For construction, a more elaborate plant was required, there being heavy cutting, embankment, and bridging to be done. On this section, up to the summit of the Rockies, there are 2 miles 3,000 feet of bridging, including eight crossings of the Bow River, one of the Kananaskis, three of Devil's Head Creek, and one trestle 250 feet long by 80 feet in height. Yet 123 miles were completed in eighty days!

Chinese Labour.

Meanwhile the line was being slowly pushed forward from the Pacific coast into the interior. From Port Moody to Kamloops the line was built by the Government, mostly with Chinese labour supplied by Wung Gee, the great Chinese contractor at Victoria. Each man received three shillings a day. This section of the line, 213 miles in length, with twenty tunnels cut through granite and hard crystalline limestone aggregating 1¾ miles, creeping along the ledges on the precipitous sides of the Fraser Canyon, and bridging the roaring torrent from promontory to promontory, provides some of the most dramatic engineering on the whole of the C.P.R. Yet it cost, exclusive of rolling stock and surveys, only £13,400 per mile. The gradient does not exceed 1·10 per cent.

There were, however, others than Chinamen in the construction gangs, especially on the higher sections, when the Company pushed on beyond Kamloops.

The Labour Problem.

"To a great extent," says Dr. George W. Campbell, who was chief timekeeper on this western stretch, "the labour problem on construction was solved by the bringing in of any kind of a human being who could handle a pick and shovel; and as the best of wages were paid, the line was flooded with some of the toughest characters on the coast, not a few of them being men who had done time at San Quentin. Police protection was an unknown quantity, Jack Kirkup being the one man who was to be depended upon to hold the lawless element in check. Of course there were gamblers and other loose characters hanging on the tail of the work, and as everything ran 'wide open' in Yale, the town was the scene of many a riotous night, and not a few men found death or injury as a consequence. The hospital for the whole grade was at Yale, and the transportation to that point of wounded men, especially from the upper divisions, was often attended with harrowing incidents."

Prospecting for a Way through the Mountains.

Kamloops was on the line of the original route selected by Sandford Fleming over the Yellowhead Pass. But Jim Hill, then one of the leading spirits in the new Company, engaged Major A. B. Rogers, an American engineer, to take charge of the mountain division from Savona's Ferry eastward, with instructions to find the shortest practicable route across the

three ranges of mountains (Gold, Selkirk, and Rocky) to the prairies. On April 29, 1881, Major Rogers and his nephew, A. L. Rogers, set out from Kamloops with ten Indian guides, engaged with the assistance of a Jesuit mission on the understanding that, if any came back without a letter of good report, his wages were to go to the church, and his chief was to give him a hundred lashes on the bare back! The Eagle Pass over the Gold Range had already been discovered by engineers who had followed an eagle's flight, but the farthest point reached in the direct route over the Selkirks across the Columbia River was at the forks of the Illecillewaet. Walter Moberly, the Government engineer who had reached this point, had only had time enough to find that the northern fork had no practicable outlet. Major Rogers resolved to try the southern fork, and, after superhuman efforts, climbed to a point of vantage which showed him that the pass was practicable.

TYPES OF RAILWAY WORKERS.

No better evidence of the tremendous task accomplished by the railroad builders could be given than in extracts from Mr. A. L. Rogers's description of this first survey:—

"Being gaunt as greyhounds, with lungs and muscles of the best, we soon reached the timber-line, where the climbing became very difficult. We crawled along the ledges, getting a toe-hold here and a finger-hold there, keeping in the shade as much as possible and kicking toe-holes in the snow-crust. When several hundred feet above the timber-line, we followed a narrow ledge around a point that was exposed to the sun. (Here four Indians fell over the ledge.) It was late in the evening when we reached the summit, very much exhausted.

Rogers's Exploratory Survey.

"Crawling along this ridge, we came to a small ledge protected from the wind by a great perpendicular rock. Here we decided to wait until the crust again formed on the snow and the morning light enabled us to travel. At ten o'clock it was still twilight on the peaks, but the valleys below were filled with the deepest gloom. We wrapped ourselves in our blankets and nibbled at our dry meat and bannock, stamping our feet in the snow to keep them from freezing, and taking turns at whipping each other with our pack-straps to keep up circulation.

"Only four hours we waited, but it seemed as if those four hours outran all time. At two o'clock dawn began to glimmer in the east, and as soon as we were able to distinguish objects we were only too glad to crawl back to the ridge. Coming to the foot of the great triangular peak we had named Syndicate, we traced the valley to the upper south fork of the Illecillewaet, and found that it

extended but a short distance in a southerly direction, and paralleled the valley on the opposite side of the dividing range, through which, we concluded, ran the waters of the Beaver, which emptied into the Columbia on the east side of the Selkirks." *

and Sandford Fleming made the first passage ever accomplished by human beings over the pass that bears his name. On that occasion, as they came in sight of the peak now called Sir Donald, Major

Rogers finds a Way.

THE GAP, IN THE ROCKIES. (*Photo, William Notman, Montreal.*)

Major Rogers then retraced his steps, and, rounding the Selkirks by a southern route, joined his engineers, who were at work upon the Kicking Horse Pass over the Rockies. In the following spring he made the summit of the pass he had found over the Selkirks from the eastern side by way of the Beaver Valley, without, however, actually crossing.

It was not until 1883 that Major Rogers Rogers declared it would be the summit of his ambition to plant on its highest point the Union Jack on the day that the first through train passed along the gorge.

Who could imagine, as he contemplates the pass from the comfortable observation car of to-day, what the engineers had to face in locating the line ?

Seventy-five miles of track were laid from the top of the Kicking Horse Pass to the

* *The Selkirk Range.* By A. O. Wheeler.

mouth of the Beaver, where Rogers Pass commences, in the year 1884.

The perilous adventures of those who located the line have been described. What of the months of patient labour endured by those who followed to carry out their bidding ? The same writer who has described the building of the prairie sections draws a picture of the life of those who, while intent only on their own needs, yet supplied the labour that made the idea a reality, earning for themselves, as has been finely said, the " bare wages of heroic toil."

Rail-roading in the Mountains.

" In the gray half-light of the early morning but little imagination would have been needed to believe that the dimly-seen forms which peopled the rocky river banks were the advance-guard of an army making its laborious way towards some naturally fortified stronghold. So at least it seemed to me as each morning I pursued my difficult and often dangerous path to the particular part of the work on which I was engaged. Here, in the mountains, the right-of-way followed the river canyons, sometimes close down to the edge of a torrent, again passing high up on the side of some tremendous valley, every here and there crossing a deep ravine, mere clefts in the gigantic towering bulk of rocks, at the bottom of which, perhaps hundreds of feet below our path, ran turbulent, brawling streams of wonderfully clear, ice-cold water.

Terrific Obstacles.

" Looking ahead, it would seem as if the grade must inevitably run straight into some one of the stupendous mountains which barred its progress, but inevitably there was some way around. Perhaps the river would be crossed suddenly, and the road lie along the farther bank, only to recross the stream a few hundred yards farther on, seeming to spring from the last foothold on the steep slope, ending in a sheer precipice, to the rocky abutment on the farther side which offered a fresh chance of clinging to its weather-beaten crags. Or perhaps a tunnel would have to be cut through a seemingly impassable spur of rock overhanging the river bed itself, and again a new valley would open up for the road to follow. Here, in the mountains, the work proceeded in the winter as in the summer, but with increasing discomfort. Steadily, steadily, every day, the white soft snowflakes fell, so soft, so wet, and so impalpable that one hardly knew whether it was snowing or raining except that, as one climbed wearily over the path back to camp in the dark, an incautious misstep proved that the depth was greater than in the morning.

" Earlier in the season the timber had been cleared from the right-of-way, and the work now consisted mainly of blasting out the stumps that remained, then picking loose and shovelling away the earth that covered the rock, and drilling and blasting out the solid rock itself down to the required level.

A Mountain Construction Camp.

" Our camp was built on a sand-bar in the river bed, which in the summer months was covered deep by the water from the melted snows, but which now, in the winter, was high and dry. Built of long logs of cedar and Douglas fir, it was about 80 feet long and some 20 wide, contained two long double tiers of bunks with a narrow passage between, and provided sleeping room for about one hundred men. It was neither so comfortable nor so clean as our prairie camps. There we had our two-man tents ; but here we were all crowded so closely that there was only just room to sleep, and no provision at all for cleanliness or comfort. The roof was made of " shakes " (long rough boards split from straight-grained cedar logs with axe and wedge). The warmth from within melted the snow, which lay several feet deep above us, making it necessary in soft weather

to wring out one's blankets carefully before rolling up in them for the night. Near by was the big dining-camp, where dwelt the cook and his half-dozen 'cookees,' and where three times a day two hundred ravenous men 'wolfed' up a plenteous supply of most excellent food; the office camps, inhabited by the contractors and their book-keepers; and all around in the silent forest, close at hand, little log-shanties held parties of two or three or four men each, mostly Italians, who preferred that way of living to the noise and rough companionship of the crowded camp.

"Long before daylight the men would start down the path, each in turn stopping before the door of the powder-house to pick up a keg of powder, or, if he was unlucky, a box of dynamite. The latter always fell to the last comers, because, besides being packed in a square box which galled the shoulders more than a keg, each package of dynamite weighed 50 lbs. as against the 25 lbs. weight of the keg of powder.

Trials of the Navvy.

"Then to the work, and perhaps a wait till it got light enough to see to smite the drill fairly on the head. The darkness cleared away slowly. The wet flakes, instead of striking invisibly, could now be distinguished from the air by sight. Next, the timber at the far side of the river loomed out from the river mists, and the mists themselves seemed to clear off and hang like a ceiling across from the trees on one side to the rough rock on the other.

"Presently the chant arose, and clink! clink! the hammers went on the drill, stopping every now and then while the drill-holder scraped out the powdered rock from the depths of the hole with a long thin rod flattened at the end. Perhaps the hole was too deep for striking, and then a long churn-drill came into use: lift, half-turn, downward drive; lift, turn again, and so on, boring its way twenty, or even thirty, feet into the solid rock.

"When a row of such holes had been drilled, and the drilling gang moved on to fresh work, the holes would be all charged with powder, fuses placed in position, and the charges tightly 'tamped' down with clay. Then, while the call, 'Fire, Fire, F-i-r-e!' warned all and sundry to get to cover, the fuses were touched off. A second later the whole face of the rock heaved outwards to the river, and the valley roared with the echoes of the terrific explosion. How the echoes rang, too! First, concussion of the blast and the near-by echoes of the woods, river, and foggy pall; then rattle and bang up and down the valley, gradually dying away to nothing, only to start into renewed life as the sound reached some distant, tremendous precipice, the new crash echoing and re-echoing from every crag that had been awakened by the first explosion, till one would swear that the whole valley was full of big guns, and that an artillery duel was at its height.

Blasting the Rock.

"When the big blast had done its work, and the débris had been cleared away, the big boulders must be smashed into fragments of manageable size.

"Accidents there must be sometimes, as in all cases where familiarity has bred contempt, but they were of very rare occurrence. We had two in that camp. In his 'shake' hut, on the hillside, the old 'Dago' who kept the dynamite warm for use was sitting one afternoon, when upon him and his fire descended a rock driven by a distant blast. A big hole in the hillside marked the place where the shack had been. Probably the old man himself never knew any more of what happened than we did of where he had gone to.

Accidents.

"The other mishap, the result of gross carelessness, was more serious. Two of the three drill-holes in the end of a 'cut' were already charged with powder, and the third was being filled, when a little piece of rock fell into the

hole and jammed some five or six feet above the powder that was already there. The weight of a long, thin tamping-stick proved quite insufficient to dislodge it, so, with unusual lack of caution, a steel drill was tried, and, of course, a spark was struck.

Disastrous Careless-ness.

"After the explosion, and while the torn bodies of the victims were being carried away, a silence fell upon that army of civilization. It is said that corpses never float in the cold waters of those mountain rivers. Certainly in this case, of those which must have been engulfed none appeared on the surface again. Neither dynamite nor drags raised them, and after a little while, when that cut had been finished and left behind, the memory of the occurrence faded.

"Amusing incidents there were too. One day a badly rattled old mule backed over the edge of the dump, cart and all, with a startled bray of dismay, into the river below. There he sat, still harnessed to the submerged cart, just his nose and eyes out of the water, and was rescued only by the united efforts of a score of men with a stout rope.

A Comic Escape.

"Railhead, from which place all supplies had to be freighted in sleighs, was anything but an imposing or populous place; but, as being the connecting link between civilization and the wilderness, it merited the sigh of relief which greeted its appearance round a bend of the trail.

"During the winter, human and other feet had beaten a hard narrow path in the snow, so that, although the snow itself was quite seven feet deep, the continual building up of the path prevented the real depth from being apparent until a misstep sent one floundering up to one's shoulders. The path itself led through primeval forests of huge cedars, which, as their spreading roots and rough churn butts were bedded deep in the even coverlet of snow, rose straight and majestic until lost in the green of their interlaced and sweeping branches. Not a breath of wind could stir in that close forest, and not a living thing showed itself, so that the screech of an occasional 'whisky-jack,' or the chatter of a woodpecker testing a dead branch which seemed likely to harbour food, gained altogether undue importance, impressing still deeper on the imagination the succeeding absolute stillness."

The Mountains in Winter.

All rock tunnelling is slow, laborious, and terribly expensive, but some of the tunnels on the path of the C.P.R. were of a peculiarly hazardous and dangerous character. The bed of solid rock which required blasting was overlaid in places with a stratum of exceedingly tenacious blue clay, the clay again being covered by gravel. Every foot of tunnelling had to be timbered up as it was driven, in order to prevent the caving-in of the clay, which would inevitably have occurred had it been left for ever so short a time without support.

Tunnel-ling.

The winter temperature on this section of the road varied from a few degrees above to about 50° below zero. "It will be easily understood," says Mr. Cunningham, the contractor's engineer, "with such a low temperature as this, how much difficulty may be caused by ice piling in the rivers about bridge piers, by springs that force their way out of the sides of cuttings and tunnels, freezing as they flow, and by accumulations of ice that form on the mountain side till they fall of their own weight."

A steam sawmill was erected on the margin of Kicking Horse Lake to cut up the timber into piles, ties, bridge and trestle timber. Here also was erected a dynamite factory, to obviate the dangers of transporting high explosives from long distances east by rail. More than 90 tons of dynamite were made at this

factory during 1884, after which year it was moved to the Columbia Valley.

The summit of the Rockies in the Kicking Horse Pass is the highest altitude touched by the road, the little station named Stephen being 5,321 feet above sea-level. Here is the boundary line between Alberta and British Columbia, marked by a rude but picturesque arch built of poles, proclaiming in wooden letters the fact that this is the "Great Divide." A sparkling streamlet of water separates into two branches, the waters of one branch flowing eastward down the Bow River into the Saskatchewan, and so through Lake Winnipeg and the Nelson River into Hudson Bay, while those of the other, with many leaps and windings, eventually reach the Pacific Ocean. The scenery around is sublime, almost terrible. On the shoulder of Mount Stephen hangs a vast shining green glacier nearly 1,000 feet in length, and showing on its outer edge a vertical depth of approximately 100 feet. The difficulties which nature placed in the way of the engineers in the Kicking Horse Pass were complicated by the political situation. British Columbia, which had entered the Dominion on the understanding that the transcontinental railway should be completed within a certain date, was threatening to secede, owing to the nonfulfilment of this compact. The descent of the

The "Great Divide."

THE "GREAT DIVIDE," AT THE SUMMIT OF KICKING HORSE PASS. *(Photo, C.P.R. Company.)*
The trench marks the boundary between Alberta and British Columbia.

Kicking Horse River is so rapid that the engineers found that enormous tunnelling operations would be necessary if the gradient of 2·2 per cent., which the Company claimed the right to maintain under their contract with the Government, was not to be exceeded. With

Heavy Gradients.

VIEW SHOWING THE LOCATIONS OF THE OLD (BROAD LINE) AND NEW (NARROW LINE) TRACKS BETWEEN HECTOR AND FIELD. (*Photo, C.P.R. Company.*)

The new location, which includes two spiral tunnels, reduces the gradient from 4·5 to 2·2 per cent.

that broad-minded policy which has always characterized this remarkable corporation, the directors waived their rights, and sanctioned a temporary line with much heavier gradients so as to keep British Columbia part of Canada. This temporary line started four miles west of the summit of the pass, and had a gradient for half a mile of 3·5 per cent., for 3¼ miles of 4·5 per cent., and for 3½ miles of 2·2 per cent.

This was by far the steepest gradient on the whole transcontinental line. In the distance of eight miles between Hector — the next station west of Stephen, which is at the summit of the pass—and Field, at the foot of the steepest part of the hill, there was a fall of 1,143 feet, most of which occurred in the four miles immediately east of Field. This gradient was known to all the railroad employees and to all the habitual travellers as the "Big Hill," and it was an awe-inspiring sight to see a heavy train, drawn and pushed by the united force of several enormously powerful "Mogul" engines, making its slow progress eastwards up the grade on a dark night when the rails were slippery with rain. The thick showers of sparks from the funnels

A Stiff Climb.

WHITE'S CREEK BRIDGE, SPUZZUM, B.C. *(Photo, C.P.R. Company.)*

and the deep sobs of the exhausts—the latter quickening suddenly into short, excited pants as the sand failed to give the wheels their necessary grip on the slippery rails—created the impression of some Titanic monster labouring to accomplish a desperate task almost too much for even its superhuman strength. At short intervals down this hill were placed switches opening into spurs of rail track leading upward into the forest. Thus, if by chance part of a train broke away on the hill, it could be caught before it gathered sufficient momentum to leap to destruction at the first sharp bend.

Safety Switches.

This gradient increased the operating costs enormously. A dozen pusher locomotives had to be kept at hand as auxiliaries, three engines being required to do the work of one on other sections of the line. So numerous were the obligations incurred by the railway immediately through traffic commenced, that it was not until the year 1908 that the original location was resumed, the contract price for the seven miles being 1,500,000 dollars. This includes two spiral tunnels and two steel bridges over the Kicking Horse River separated by only a few hundred yards.

A Fresh Location of Track near Hector.

On the section from the top of the Kicking Horse Pass to the mouth of the Beaver ($73\frac{3}{4}$ miles) there are seven tunnels, totalling 2,152 feet. The Kicking Horse River is crossed nine

times, six of these crossings being within a distance of twelve miles. The winding nature of the road can thus be easily imagined. At first, of course, the bridges had to be made of wood; but to-day they have been, almost without exception, replaced by permanent structures of steel and concrete. The total length of bridging and trestle work from the summit to the first crossing of the Columbia River (62 miles) was 8,039 lineal feet.

INSPECTING THE LINE ON VANCOUVER ISLAND.
(Photo, C.P.R. Company.)

"The general system of building trestles and bridges was as follows: After the ground had been cleared of standing trees and fallen trunks, piles were driven into position by the pile-driving gang. The main timbers, such as sills, posts, and caps, were hewn in the immediate neighbourhood, framed and erected ready to receive the track-stringers. When the track, as it was being laid, arrived at such a structure, a car laden with the requisite number of stringers and floor timbers was run forward to the extremity of the rails, unloaded, and the pieces placed in position by a gang of bridgemen. This generally involved some delay to the track-laying, but by proper organization and promptness the delay was small. It could usually be arranged that any large structure could be completed by the bridgemen at night. It was impossible to transport heavy bridge timbers by wagon over the wagon road, as had been done on the prairie section of the line.

Building Bridges.

"The Howe truss, in spans varying from 100 to 150 feet, was chiefly used......To obviate the delay to track-laying, which would have occurred had the truss material been run forward to the end of the track at each bridge, the truss erected, and the track then laid across, it was deemed expedient to bridge the river by temporary pile structures at the various points, and to erect the trusses at greater leisure, after the material had been brought forward by the train, and the track-laying had passed on. In a few exceptionally difficult places, however, the permanent trusses were erected in the first instance. The piers carrying these trusses were formed of timber cribwork filled with stone."

The piles were driven with a hammer weighing 2,000 lbs., until there was not more than ½-inch penetration under a blow given by this weight falling through 25 feet. The five pile-drivers at work drove on the average ten to fifteen piles per day to a depth of 10 feet into the ground.

Pile-driving.

The greatest feat in trestle bridging was, however, performed near Bear Creek, about

eight miles east of the summit of the Selkirk range. Here the railroad, at an altitude of

Stony Creek Bridge.

3,673 feet, crossed several narrow gorges carved out by foaming rivers. The greatest of all these bridges is that across Stony Creek, a leaping torrent of water flowing at the bottom of a narrow cleft in the rock 300 feet below the surface of the road.

PILE-DRIVING THROUGH THE ICE FOR BRIDGE CONSTRUCTION.

The original structure was at the time the premier timber railway bridge in the world, being 296 feet high by 450 feet long. It was a continuous Howe truss of four spans, 161, 172, 86, and 33 feet respectively, supported by wooden towers 200 feet high on concrete footings. The present structure, erected in 1893, is a steel arch truss, with a span of 336 feet and a rise from the abutment of 120 feet.

The frosts of winter were at once a great help and a serious hindrance to the work of bridging the rivers and ravines—a help be-

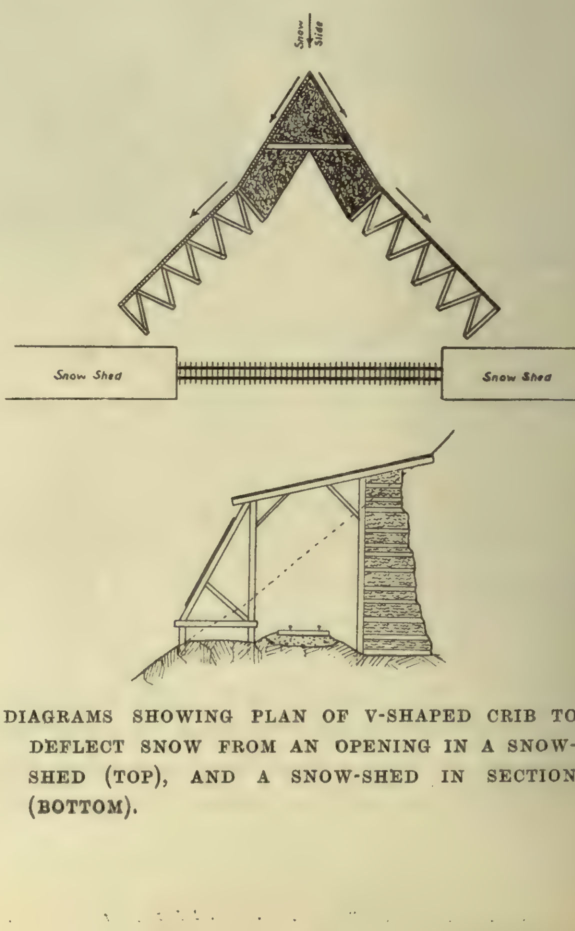
Cold and Dangerous Work.

cause the solid ice which covered the water made the task of pile-driving and erecting the superstructure much simpler and quicker. Holes were cut in the ice for the piles, which were drawn from the surrounding or close-by woods, and quickly driven in solidly. Light "false work" (temporary scaffolding) was then erected upon the ice to support the sills of the bridge floor until the truss beams could be placed in position, holes for the rods bored, and the nuts screwed tight to make all safe. For the men who did the work it was an unpleasant business, walking on a slippery stringer, balancing on an ice-covered plate, or perched on a truss 30 or 40 feet above the ice. Those who have experienced the nervous thrill attending recovery from a foot-slip under such conditions remember also no doubt the bite of the icy wind as they slowly bored an auger hole through eleven or twelve inches of frozen fir, and presently hung over the same beam, directing with both hands the end of a long quivering truss rod.

The great feature of the Rogers Pass is the long line of snow-sheds—solid structures of cribwork and piling, filled in with stones, and placed wherever a snow-slide

Snow-sheds.

appears on the mountain side. If built continuously, they would stretch for nearly six miles. They are



DIAGRAMS SHOWING PLAN OF V-SHAPED CRIB TO DEFLECT SNOW FROM AN OPENING IN A SNOW-SHED (TOP), AND A SNOW-SHED IN SECTION (BOTTOM).

so constructed as to have the roof on the plane of any possible avalanche, and the train can therefore pass through them in perfect safety.

INTERIOR OF A SNOW-SHED. *(Photo, William Notman, Montreal.)*

Types of Snow-sheds.

The sheds are of five types, the chief of which is as follows: The uphill side is held by a retaining crib of cedar logs. The rafters are supported at one end by this crib, and at the other rest on a framed bent, the middle of the rafter being supported by struts. As a rule the uprights are five feet apart between centres, but at points where unusually severe slides may be expected this distance is reduced to four feet.

As a shed is a valuable structure, and also subject to fire, ample precautions have been taken. A complete system of piping extends throughout the shed, and the shed itself is broken into short lengths separated by "fire-breaks." These breaks are covered by split fences, which consist of heavy V-shaped cribs, to guide the slide over the adjacent sheds.

Another remarkable piece of engineering in the Illecillewaet Valley is the section called the "Loops." A correspondent of *The Times* thus describes them :—

The "Loops."

"First the line runs southwards along the side of the gorge towards the glacier; then it crosses a high bridge and curves back on the other side, coming out near where it started, but on a lower level. Next it curves round into the second ravine, swings across it, and comes back again at 120 feet lower level, and yet only 130 feet farther down the pass. There it doubles upon itself and crosses the river, immediately recrossing again. Here are six almost parallel lines of railway in full view, each at a lower stage, and each made up largely of huge trestle bridges."

Proceeding eastwards, the trains have to climb a steep gradient round the loops, and so great is the distance that has to be travelled to make the rise, and so much time is necessary to accomplish the distance, that it is quite possible for an active man to drop off a

train at one point, and by quickly climbing a hundred feet or so of steep bank, reach a point to gain which the train must travel a mile or more.

The crossing of the Gold Range by the Eagle Pass was a simple matter compared with the Titanic engineering accomplished on the Kicking Horse and Rogers Passes; but here it was that the drama drew to its climax. The rails being built from the Pacific and the Atlantic met at Craigellachie. One cannot do better than describe this meeting in the words of the great engineer who was present on that occasion, Sir Sandford Fleming: *

The Rails meet.

"Early on the morning of November 7 (1885) the hundreds of busy workmen gradually brought the two tracks nearer and nearer, and at nine o'clock the last rail was laid in its place to complete the railway connection from ocean to ocean. All that remained to finish the work was to drive home the last spike. This duty devolved on one of the four directors present, the senior in years and influence, he who is known the world over as Lord Strathcona. No one could on such an occasion more worthily represent the Company by taking hold of the spike hammer and giving the finishing blows.

"It was indeed no ordinary occasion. The scene was in every respect noteworthy, from the groups which composed it and the circumstances which had brought together so many human beings in this spot in the heart of the mountains, until recently an untracked solitude. The engineers, the workmen, every one present, appeared deeply impressed by what was taking place. It was felt by all to be the moment of triumph. The central figure—the only one in action at the moment—was more than the representative of the Railway Company. His presence recalled memories of the Mackenzies, Frasers, Finlaysons, Thompsons, M'Leods, MacGillivrays, Stuarts, MacTavishes, and M'Loughlins, who in a past generation had penetrated the surrounding mountains. To-day he is the chief representative of a vast trading organization in the third century of its existence.

A Dramatic Scene.

"The spike driven home, the silence for a moment or two remained unbroken. It seemed as if the act now performed had worked a spell on all present. Each was absorbed in his own thoughts. The silence was, however, of short duration. The pent-up feelings found vent in a spontaneous cheer, the echoes of which will long be remembered in association with Craigellachie.

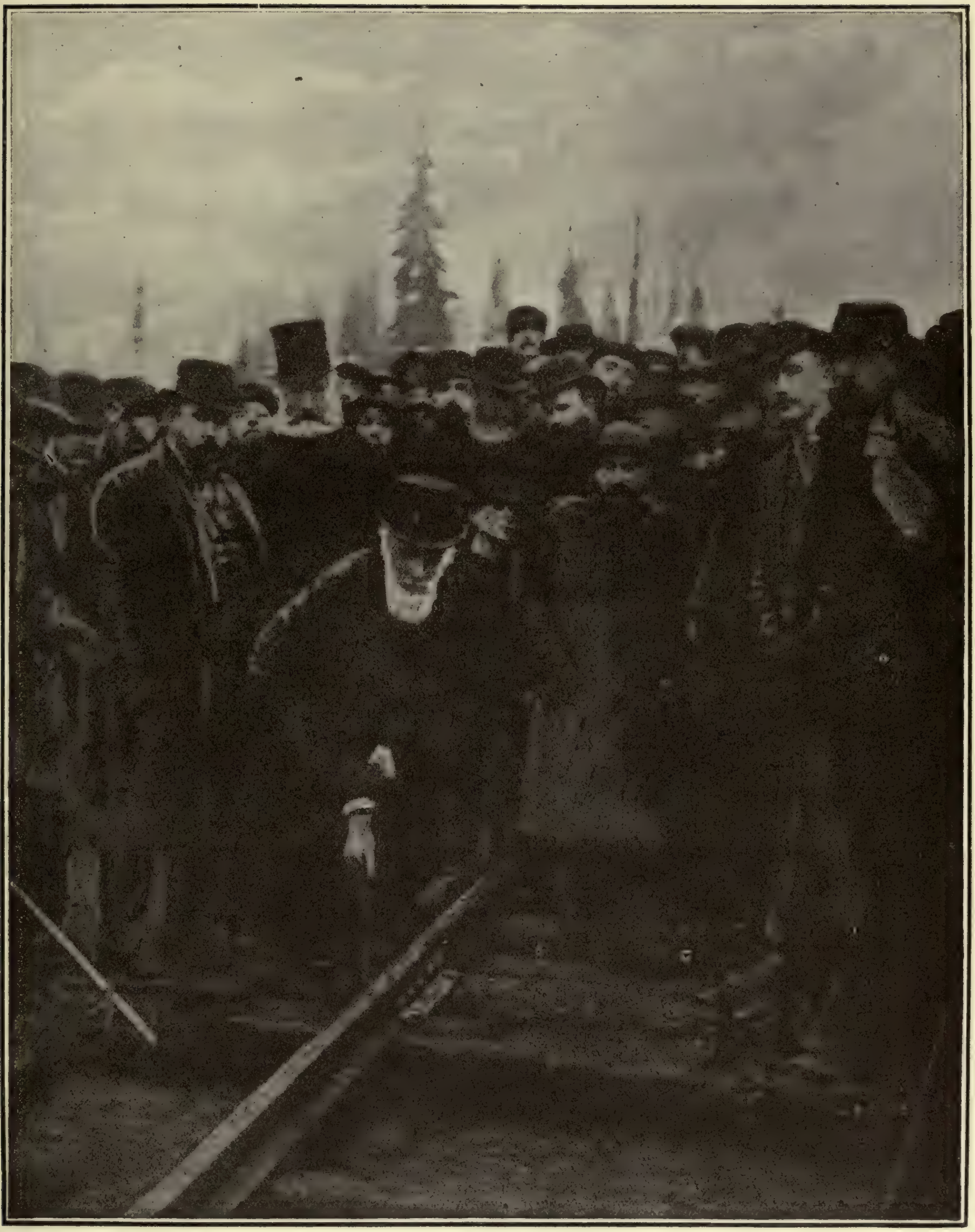
The Last Spike driven.

"In a few minutes the train was again in motion. It passed over the new-laid rail amid further cheering, and sped on its way, arriving the following morning at Port Moody, where a connection was made with the Pacific on November 8, 1885."

The feat of building the transcontinental railway, with which we are here mainly concerned, was now achieved. The tale would be but incomplete without a glance at what has been done since then. It is not often given to those who play the principal parts in such achievements to see, in their own day, the child of their hands and brains grow to such enormous proportions and loom so large in the history of the world's progress. At the date of the driving of the last spike the site of the present city of Vancouver was an almost untrodden forest. Now, with its population of 100,000, and its magnificent landlocked, mountain-sheltered harbour—the port for the yacht-like *Empress* steamers that ply in the great Pacific—Vancouver is counted among the gateways of the world.

The valleys of British Columbia and the vast prairies of the North-West Territories were then sparsely tenanted by a few cattle-

* *Canadian Alpine Journal*, Vol. I.



LORD STRATHCONA (THE HON. DONALD A. SMITH) DRIVING THE LAST SPIKE OF THE CANADIAN PACIFIC RAILWAY AT CRAIGELLACHIE, NOVEMBER 7, 1885.

Behind him are Sir Sandford Fleming (with white beard and tall hat) and Sir William Van Horne (in square felt hat).

(Photo, C.P.R. Company.)

THE C.P.R. SIDINGS AT WINNIPEG. (*Photo, C.P.R. Company.*)

The largest in the world; 120 miles of track.

closes navigation for the season on those inland waters, the railroad is overtaxed in the attempt to cope with the east-bound trade till spring opens the lake ports again.

In 1880 Canada meant some quietly prosperous eastern provinces, an isolated, sparsely settled western province, and a vast undeveloped hinterland. The now solid east and the progressive west derive their prosperity mainly from the great railway enterprise which has turned the prairies into wheat-fields, and substituted busy farmers and their live stock for the Indian and the bison.

We have glanced at the reasons that compelled construction to be undertaken when but few men thought the time ripe or the enterprise justified. We have studied in some detail the actual building of the "Transcontinental"—the arduous journeys and ad-

men and horsemen, while the mining wealth of "B.C." was but dimly appreciated. Winnipeg, the present populous city of the Middle West, was but in its childhood, waiting for the prairies to be peopled and for the coming of the yearly tide of wheat to build its solid business streets and its present prosperity.

What the C.P.R. has done for Canada.

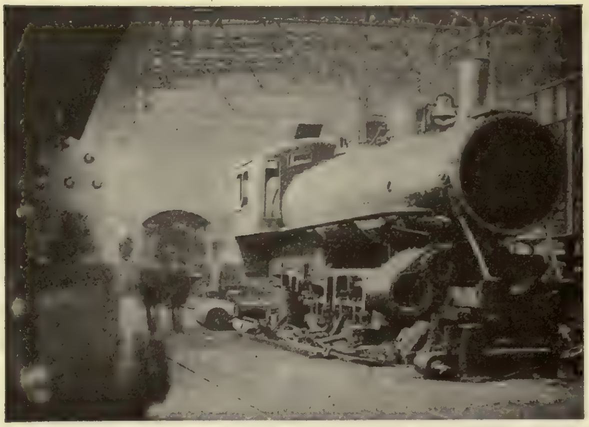
Now these same valleys are filled with farms and orchards; the great neighbouring plateaus—tapped by branches from the parent line—are dotted with busy centres of activity. Their fertility and the wealth of the mountains and of Northern Ontario are attested by the long fleets of grain and ore steamers that follow each other swiftly across the lakes and through the riverways and canals to the ocean ports on the Atlantic. By Sault Ste. Marie, then an Indian village, now passes each year a tonnage of shipping thrice that which threads the Suez Canal. When ice

GRAIN ELEVATORS AT FORT WILLIAM. (*Photo, C.P.R. Company.*)

They have each an average capacity of 1,500,000 bushels.

ventures of the engineer explorers, and the steady toil of those who drilled and blasted the rocks, hewed and placed the timbers spanning the rivers, creeks, and ravines, and finally laid the steel. We have noted the development of the whole country that has followed the gift of communication and transportation between its various provinces. We have considered the ocean fleets on the Atlantic and the Pacific which make it possible for the C.P.R. to carry passengers under their own care the whole way from England to Japan and to China. Before concluding, we should mention the Company's great hotels. Perhaps these might be omitted from a story of which the avowed object is to deal with its subject from an engineering point of view, were it not that, to ensure the successful completion of at least one of them, the Company not only built the hotel itself, but made the land upon which it stands.

The Great Hotels of the C.P.R.



REPAIRING A C.P.R. ENGINE. (Done once every four years.)

AN ADVERTISEMENT TRAIN.

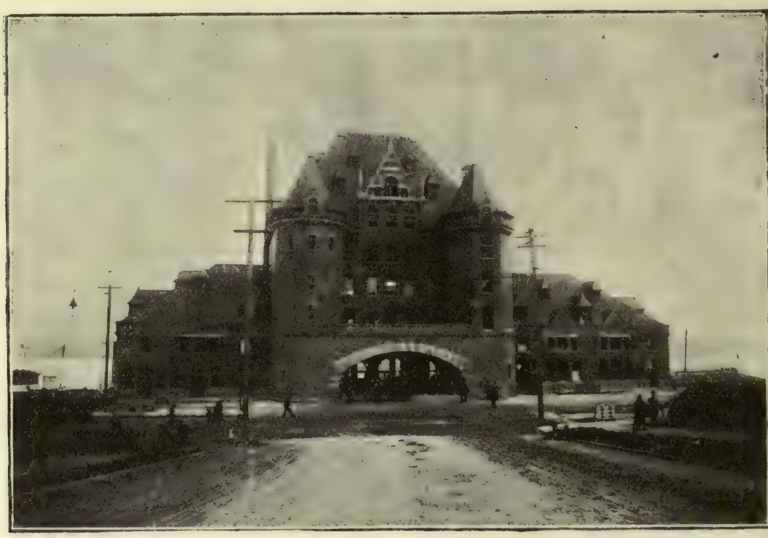
The Empress Hotel at Victoria.

The city of Victoria was formerly cut in two by James Bay, an arm of the sea which, uncovered by the retreating tide, was at low water merely an expanse of mud. On the western shore of the bay stood the main business portion of the city, and on the east, facing the harbour, the imposing Parliament buildings which the province of British Columbia erected with such lavish expenditure. The bay between the two was spanned by a fine bridge separating the harbour on the one side from the tidal flats on the other. Where once the residents of Victoria shot ducks there now stands the westernmost of the C.P.R. hotels. To make its erection possible a strong retaining wall was built to protect the bridge, and the flats were filled with mud pumped from the bottom of the harbour. The pressure exerted by this sea of mud while it dried was so great that the massive stone walls were cracked and had to be again strengthened to ensure the safety of the bridge itself. Deep into this "made" ground the foundations of the hotel were sunk, the excavations having meanwhile to be protected by massive piling. The magnifi-

cent Empress Hotel, now standing on what was once James Bay and overlooking the western capital and the western ocean, constitutes a worthy mate for the Château Frontenac commanding historic Quebec and the beautiful St. Lawrence.

The C.P.R. was one of the pioneers of the policy of building railroads in advance of settlement. In the old world, population became dense before the discovery of steam power, and the trade was assured before railway ventures were entered upon. Therefore the wonderful results of the last twenty years have seemed the more spectacular even while the promise for the future still remains only half fulfilled.

"We all know how the C.P.R. has helped to make a nation." Yet very few people, in the days when the inland provinces of Canada were thought to be habitable for coyotes and Indians only, knew that in building a railroad they were building a nation, and forging one of the strongest of all the links in the chain which now binds together a mighty Empire.



VANCOUVER STATION, B.C. *(Photo, C.P.R. Company.)*

TRANSPORTER BRIDGES.

Fig. 1.*

BY JOHN J. WEBSTER, M.Inst.C.E.

An Interesting Account of the Latest Development of the Steel-built Bridge

THERE are no records of the earliest history of bridge-building, and the word is not mentioned in the Old Testament; but ever since man appeared upon the earth there is no doubt that, in his natural inclination to wander away from his home, either from a love of exploration, or in the pursuit of game, or most probably with the intention of annexing his neighbour's land, he would, before travelling very far, meet with some obstacle, such as a stream or a river. If the stream was too deep to be forded, possibly nature came to the

Development of Bridges.

* *The Car of the Runcorn Transporter Bridge making a passage. On one occasion this car had 800 passengers on board.* *See page 297.*

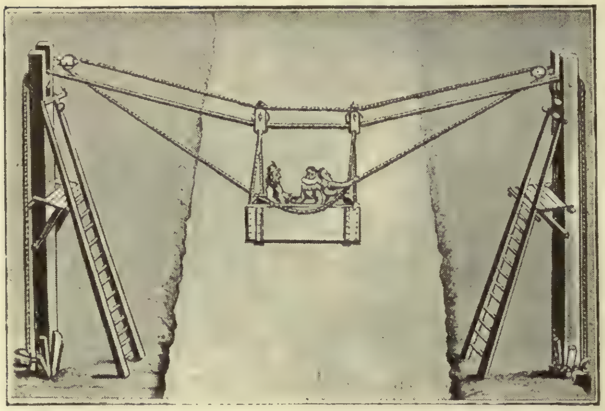


Fig. 2.—AN ANCIENT TRANSPORTER BRIDGE.

wanderer's assistance, and a fallen tree enabled him to continue his journey; and from this fallen tree, or a plank thrown across a stream, have been evolved, by most interesting and instructive stages, the gigantic structures now to be seen in all parts of the world.

The primary object of any bridge is to enable road or railway traffic to be carried between two points across some intervening obstruction; and considering the numerous types of bridges now available, the question to be decided is, which particular type is best adapted for certain conditions of site and traffic? One of the problems which has very often to be dealt with is the best method of providing facilities for taking the traffic across a navigable river.

A fixed bridge which, under ordinary circumstances, is the best form to adopt, would be quite out of the question for a navigable channel; for it would have to be of such a height to clear the ships' masts that, in most cases, the cost of construction and the purchase of land for the long approaches would quite preclude its adoption, unless there were high banks on both sides of the channel. It would therefore be necessary to adopt some form of movable bridge; and to within comparatively recent years this form has been either a swing, draw, or a bascule bridge.

These three types of bridges answer their purpose as far as the accommodation of the cross-road traffic and the free passage of the vessels are concerned, but the opening span has to be in a definite position and of somewhat limited dimensions. In many important estuaries and rivers the vessels go up and down the waters under their own sail, and to be able to make for a definite opening requires skilled navigation not unattended by great risks, especially if there be a strong tide running, as often happens.

It would therefore appear that, for any river or estuary navigated by large vessels to be crossed satisfactorily by a bridge, this last should be of a type which does not impede navigation at all, and gives ample clearance for the masts. A high-level bridge can be adopted only where the banks on either side of the water are of sufficient height to reduce the length and consequent cost of the approaches. The Clifton Suspension Bridge over the Avon at Bristol is a good illustration. Such physical conditions obtain very seldom, however.

All these difficulties of site and navigation are overcome by the adoption of a Transporter

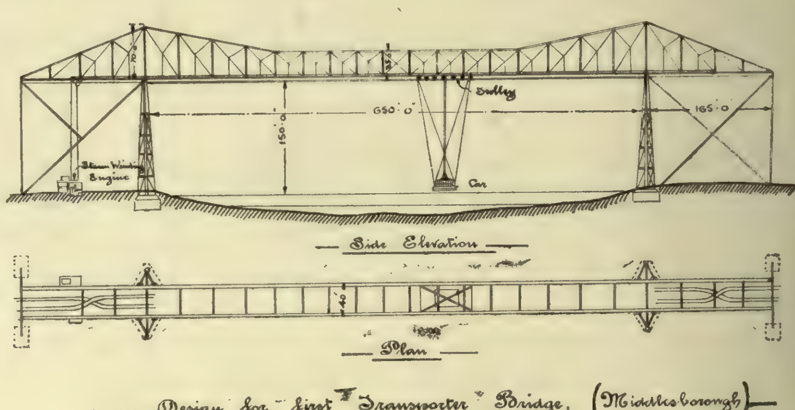


Fig. 3.—DESIGN FOR MIDDLESBOROUGH BRIDGE.

bridge, which is simply a girder, fixed or suspended at a height sufficient to clear the tops of the ships' masts, spanning the entire width of the river or estuary, and resting upon supports on either side. To the under side of the girders are attached rails, along which runs a trolley, supporting by vertical cables a car, with its deck at the level of the approaches. The trolley is actuated by certain gearing to take the car backwards and forwards as desired. This is the main principle of the transporter bridge, and the different methods of utilizing it have given rise to numerous designs of structure adapted to the various conditions of site and traffic and to the ideas of different engineers.

The Transporter Bridge.

Before describing the various types more particularly, it may be of interest to refer to an illustration (Fig. 2) which is the copy of a very old print in the possession of the Charlottenburg Museum at Berlin of the Faust Wranczi Bridge—a transporter bridge of a primitive kind, as the people in the car have to "work their passage," instead of being taken across by steam or electric power.

A Primitive Transporter.

The first transporter bridge designed on practical lines was made by Mr. Charles Smith of Hartlepool, who, in 1873, planned a bridge to cross the river Tees at Middlesborough. From financial or other reasons the scheme fell through, and the bridge was never built. (Fig. 3.)

Since the design of Mr. Smith for the transporter bridge at Middlesborough, no attempt was made to adopt this system until many years later, when Signor A. de Palacio, an architect of Bilbao, in conjunction with Monsieur F. Arnodin, patented the system, and in the year 1893 designed and erected a bridge at Portugaleti, near Bilbao. (See Fig. 4.) Although the principle of carrying the traffic is the same as in Mr. Smith's original design for the projected Middlesborough bridge, the construction is entirely different, the supporting columns being fixed, and not hinged, at the bottom. Also, in place of the cantilever girders, the bridge has the form of a suspension bridge with stiffening girders. The distance apart of the columns is 528 feet, centre to centre; and the clear height above high-water level is about 148 feet. An auxiliary cable is fixed to the end of the stiffening girders and secured to the anchorage, to control longitudinal movements of the girder. As the towers swayed to a considerable extent during heavy gales, steel wire guys were attached to them, fore and aft, as shown in the illustration (Fig. 4). This extra support has, however, not proved to be necessary in any of the more recent structures.

The Portugaleti Bridge.

A transporter bridge of similar type to the one at Portugaleti was constructed at Bizerta, in Tunis, by Monsieur F. Arnodin, having a span of 360 feet, and a clear height above the water-level of 149 feet. The car was about 30 feet long by 25 feet wide, and was actuated by rope gear driven by a winding engine. Owing to the extension of the harbour works at Bizerta, it has been found necessary to take down this bridge; but there is a probability of it being erected elsewhere, and possibly when the harbour works are completed a larger bridge will be constructed near the site of the old one.

In the year 1897 a transporter bridge was built at Rouen, the type being very similar to those previously described and designed by Monsieur F. Arnodin (Fig. 5). The bridge crosses the river Seine at a point about half a mile below the Pont Boieldieu, and has a span of about 472 feet. The car is actuated by rope gearing, but as electric current was available in the town, the machinery is driven by electric motors fixed on the top of the

Rouen Bridge.

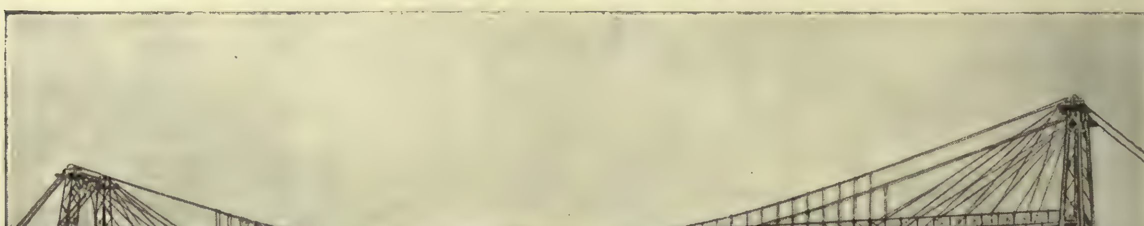


Fig. 4.—PORTUGALETI TRANSPORTER BRIDGE.

Fig. 5.—ROUEN TRANSPORTER BRIDGE. 472 FEET SPAN; HEIGHT ABOVE WATER, 168 FEET.

Fig. 6.—NEWPORT TRANSPORTER BRIDGE. 592 FEET SPAN; HEIGHT ABOVE WATER, 177 FEET.

car, the wire hauling ropes passing round a drum with spiral grooves. The centre of the car is used for wheel traffic, the two overhanging portions being covered for the use of passengers, and divided into first and second classes. There is a staircase leading to the top of the towers, 280 feet high, whence a magnificent view of the surrounding country is obtained.

The most important example of this type of bridge—with hinged tower legs and girder suspended from cables—is the one built at Newport, Monmouthshire, over the river Usk, commenced in 1903, the engineers being Mr. Robert H. Haynes and Monsieur F. Arnodin. The bridge is shown in elevation in Fig. 6. The span from centre to centre of towers is 645 feet, the clearance between the towers 592 feet, and the clear headway above high-water level 177 feet. The car, 33 feet long by 40 feet wide, is electrically driven by two motors of 35 horse-power each, actuating by continuous rope gearing the trolley running underneath the stiffening girder, from which is suspended the car. This trolley is 104 feet long, and is fitted with sixty steel wheels.

Newport Bridge.

The suspension cables are sixteen in number, four inside and four outside each of the stiffening girders, and each contains 127 wires and weighs 4 tons. There is an equal number of anchor cables or backstays, which are not continuous with the main suspension cables. As the backstays make a sharper angle at the top of the towers with the horizon than do the suspension cables, the stress on them is greater, and consequently they have a larger sectional area, that of the suspension cable being 3·9 square inches for each cable, against 4·27 square inches for the backstay. The weight of the suspension cables and backstays is 176 tons. The backstays are secured to large blocks of masonry for anchorage, each block containing 35,800 cubic feet of masonry. The two towers weigh 580 tons, the stiffening girders 560 tons.

The foundation piers are placed in groups of four on each side of the river. They consist of masonry with steel shoes or kerbs, which

Fig. 7.—NANTES TRANSPORTER BRIDGE. FLOATING THE CENTRAL GIRDER.

were sunk by means of compressed air, and contain each about 19,500 cubic feet of masonry and concrete. The cost of the bridge was about £70,000.

The bridges previously described are all of one type, each having a stiffening girder suspended from steel cables, and towers hinged at the base; but as it is not always possible to obtain space for the great masonry anchorages, the above designs sometimes have to be modified.

The Nantes Bridge.

In the year 1902 a bridge was commenced at Nantes by Monsieur F. Arnodin, and completed in the following year. Its span is 465 feet between the centres of the towers, and it clears the water by 165 feet. The design of this bridge differs from those already described in the method of carrying the main girders. As seen in our illustrations (Figs. 7, 8, and 9), each of these girders is subdivided into three parts, of which two are suspended directly from the tower by raked cables. The outer ends, projecting 83 feet landwards, are anchored vertically to the ground. The 113½-foot space between these cantilever girders is spanned by a central girder, raised into position when its two supports had been completed. The cantilever principle facilitated erection greatly, and was subsequently employed for a transporter bridge of 545-foot span built at Marseilles.

Another form of transporter bridge is that designed by Mr. C. A. P. Turner for crossing the ship canal at Duluth, Minnesota. This design is entirely different from the French bridges: the towers are fixed at the bases, and the towers and girders combined form one rigid structure. The main girders are 54 feet deep at the centre, and 30 feet deep at the ends. The clear span is 393 feet 9 inches; the clear headway from surface of canal to under side of girders 135 feet. Like the towers and girders, the car suspenders also are rigid, and not attached to the trolley frame by means of wire suspenders. The trolley is electrically driven by rope gearing in a manner somewhat similar to that used for the other

Fig. 8.—NANTES TRANSPORTER BRIDGE. RAISING THE CENTRAL GIRDER.

Fig. 9.—NANTES BRIDGE COMPLETED.

Fig. 10.—MARSEILLES TRANSPORTER BRIDGE, PARTLY BUILT. 545 FEET SPAN; HEIGHT ABOVE WATER, 165 FEET.

bridges. The cost of the structure is about £22,000.

The largest transporter bridge ever erected, and the first of its kind in Great Britain, is the one crossing the river Mersey and the Manchester Ship Canal between Widnes and Runcorn, designed by Mr. John J. Webster, M.Inst.C.E., of Westminster. (See Fig. 11.) This bridge has a span of 1,000 feet between the centres of the towers. The clear height (82 feet) from high-water level to the under side of the girders is governed by the L. and N.-W. Railway Bridge, crossing the river about 150 yards below, the girders of which have only 75 feet clearance. The principle of the bridge is the same as that of the other transporters, but the details of construction are entirely different.

Runcorn Transporter Bridge.

Two towers, built up of steel angle bars and plates, rise on each side of the river. They are square in plan, with braced legs at each corner, the width at the base being 35 feet and at the top 9 feet. The outside profile is slightly curved. The two towers are braced together horizontally and diagonally, and bolted to the top of cast-iron cylinders 9 feet in diameter, placed 30 feet apart, centre to centre. (Fig. 12.) On the Widnes side of the river the cylinders were attached to the rock, which is exposed at low water; on the Runcorn side, eight cylinders had to be sunk through the bed of the Ship Canal to a depth of about 35 feet under compressed air before the solid rock was reached. (Fig. 13.) When the foundation cylinders had been fixed in position, and braced together in clusters of four with strong steel horizontal and diagonal ties, they were filled with Portland cement concrete. The cylinders are protected by greenheart fenders, both in the river and in the Ship Canal.

Fig. 11.—THE RUNCORN TRANSPORTER BRIDGE, THE LARGEST OF ITS KIND. IT HAS A SPAN OF 1,000 FEET, AND CROSSES THE MERSEY AND THE MANCHESTER SHIP CANAL.

The Cables.

There are only two cables, one over each pair of towers, and instead of hanging vertically, as in the other bridges, they are "cradled"—that is to say, they are drawn nearer to each other at the centre of the bridge than they are at the towers. The main cable and backstays leading to the anchorages are all in one piece, and consist of nineteen steel ropes or strands bound together, each rope being built up of 127 wires ·16 inch in diameter. Each cable consists of 2,413 wires, and weighs about 130 tons.

At the points where they pass over the towers the cables rest upon large cast-iron saddles, supported upon rollers to permit small movements. A side view of the actual saddle is shown in Fig. 14. The top of the saddle is grooved to receive the cable. As the backstay leaves the tower at a sharper angle than does the main cable, the tendency of a load on the central span is to move the saddle riverwards. This tendency is overcome by clamping the cable to the saddle with four plates and twenty-four bolts. Owing to gross carelessness in not seeing that these bolts were tight, an accident happened the day after the bridge was opened, when it was found that all the nuts were quite loose, and had allowed the saddle to slip in consequence. The method of attaching the nineteen ropes to the anchorage is shown in Fig. 15, where the ends are to be seen fixed to screwed adjustable couplings passing through steel forged crossheads, thence by links to the anchorage. All the nineteen ropes are gathered together at a point about 60 feet

Fig. 12.—BUILDING THE TOWERS OF THE RUNCORN TRANSPORTER BRIDGE WITH THE AID OF A STEAM-CRANE PERCHED ON A TEMPORARY SCAFFOLDING.

from the anchorage and firmly clamped, so as to form one cable.

The stiffening girders project fifty-five feet beyond the towers at each end, to enable the car to enter between the tower legs.

The Car.

They are thirty-five feet deep throughout, and are hinged at the centre of the span to overcome temperature stresses. The trolley runs on the outer edge of each bottom flange of the girders, and consists of a flexible frame moving on thirty-two cast-steel wheels, four of which are drivers. Suspended from this frame is the car, 55 feet long by 24 feet wide, made specially strong to carry heavy machinery—boilers, etc.—manufactured at the local works. (Fig. 1.) The car can take four two-horse farmers' wagons and 300 people at the same time, and 500 to 600 passengers frequently cross at one time. On a certain occasion, just before a football match, there were nearly 800 people on board the car, packed together like sardines.

The car is driven direct by two electric motors of 36 B.H.P. fixed to the trolley, this being the first instance in which rope gearing has been dispensed with. The car is fitted with a magnetic brake, and is under perfect control of the man in the cabin on the top of the car. The motors can be driven either "in series" or "in parallel," the latter system transporting the car in about 1¾ minutes. The present traffic does not, however, demand this speed, and the motors are run "in series," the time of crossing being thus a little over three minutes, varying with the pressure and direction of the wind.

The total weight of the towers and the stiffening girders is about 1,400 tons, and the total cost of the bridge, including the viaduct approaches and Parliamentary expenses, was about £133,000.

The approximate leading dimensions of the chief transporter bridges may be summarized as follows :—

Name of Bridge.	Date of Erection.	Span.	Clear Height above Water-level.	Size of Car.
Mr. C. Smith's design	1873	650 ft.	150 ft.	——
Portugaleti	1893	528 ft.	148 ft.	26 ft. 6 in. by 20 ft. 6 in.
Rouen	1897	472 ft.	168 ft.	43 ft. by 33 ft. 6 in.
Bizerta	1898	360 ft.	149 ft.	30 ft. by 25 ft.
Martrou	1899	461 ft.	180 ft.	46 ft. by 38 ft.
Nantes	1902	465 ft.	165 ft.	39 ft. by 33 ft.
Widnes and Runcorn	1903	1,000 ft.	82 ft.	55 ft. by 24 ft.
Newport (Monmouth)	1904	592 ft.	177 ft.	33 ft. by 40 ft.
Marseilles	—	545 ft.	165 ft.	38 ft. by 33 ft.
Duluth	1904	393 ft. 9 in.	135 ft.	54 ft. by 30 ft.

In designing transporter bridges, many interesting points, governed by the site and other local conditions, and, as often as not, by financial requirements, have to be taken into consideration.

The Designing of Transporter Bridges.

About the advantages of this type of bridge under certain conditions there can be no doubt, although many people are still sceptical. It is generally found that those people who have never seen such bridges, and do not understand how they are worked, have most to say against them, and many good schemes have been blocked by the profound ignorance of one or two "clever ones." All the bridges erected hitherto have proved to be very satisfactory, so far as accommodation and creation of traffic is concerned, and most of them have also been successful financially.

The methods of erection of these bridges is very interesting. The foundations are somewhat similar to those of ordinary bridges, and

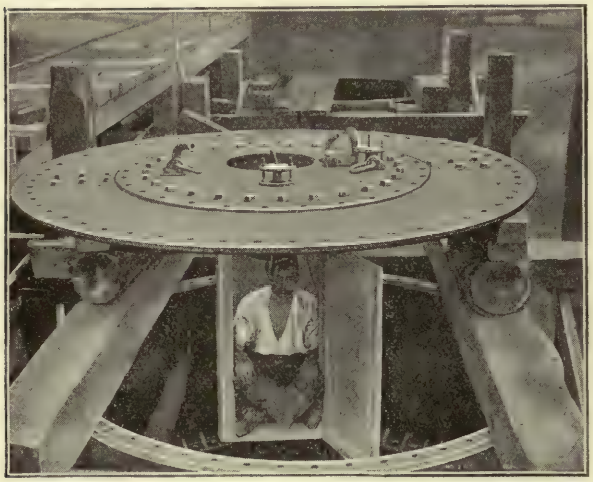


Fig. 13.—AN AIR-LOCK AT THE TOP OF ONE OF THE EIGHT CYLINDERS SUNK FOR THE FOUNDATIONS OF THE SOUTH TOWER OF THE RUNCORN TRANSPORTER BRIDGE.

do not present any special difficulties. In building the superstructure, the electric crane used in the French bridges and at Newport was very useful. It was of light construction, and was easily raised as the work proceeded, so that the working cost per ton of material lifted came out very low. The method adopted at Widnes was different. There a steel stallage was erected between the towers, and a steam crane with a long movable jib was erected on the top, the lift being sufficient to fix the cupolas on the top of the towers. Electric power would have been used in preference to steam had it been available on either side of the river.

Points about Cables.

The construction of cables is a matter on which opinions differ. In most of the French transporter bridges the main suspension cable is independent of the backstays. This is theoretically correct, for unless the backstays and the main cable leave the tower at the same angle, the stress in the backstays is greater than in the cable, and consequently the backstays should have a larger section. This arrangement requires, however, many more connections and adjustments, which may counterbalance any advantage of cost gained by reducing the section of the main cable.

The French cables are compounded of a number of ropes, the advantages claimed being facility in replacing the cables and interchangeability; but as the cables, if properly maintained, will last considerably longer than the rest of the structure, the necessity for interchanging should not occur. Again, the numerous cables expose considerably more area to the atmosphere than a single cable of the same gross section, and in an atmosphere laden with chemical fumes such as exist at Widnes this is an important consideration.

Erecting Cables.

In erecting the cables there is no advantage in having a number of smaller cables, because a single cable is formed by hauling up a single strand at a time and binding all the strands with strong steel clips. At Widnes a "Blondin" rope was stretched across first, upon which ran "carriers," to which the strands of the main cables were attached, one at a time, to be hauled into position by means of a steam winding engine. The nineteen strands making up the cable were carefully adjusted to the correct curve, and then firmly bound together. When the cables of the Runcorn Bridge were ready to receive

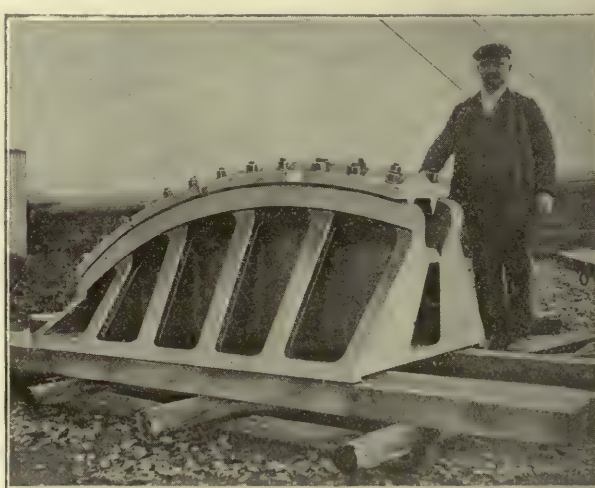


Fig. 14.—ONE OF THE SADDLES TO CARRY THE CABLES OF THE RUNCORN TRANSPORTER BRIDGE.

the suspenders and the stiffening girders, a curious thing happened, which illustrated the theory of interference of wave action. A strong gale set up a vibration in the cable, which was supported at the ends only, the vertical wave being about ten feet high at intervals of four seconds. In the following week a much stronger gale sprang up from the same quarter, but there was *no movement of the cables.* In the first case the gusts of wind—which are not continuous—must have synchronized with the natural vibration period of the cable, but, in the second case, have worked antagonistically.

Propulsion of the Car.

An important question is the method of running the car. In the case of all the French bridges and the Newport Bridge the car trolley is hauled backwards and forwards by endless ropes. This, the old method of working travelling and other cranes, tramways, etc., has been abandoned in favour of direct traction, and would appear to be the better system both theoretically and practically. The continuous stretching of the cables must cause considerable trouble, even if appliances are adopted for taking up the slack; and the cables have to be supported and released as the car travels along, which involves the use of devices that are all liable to get out of order. There is certainly a slight saving in the weight of the car and trolley to be propelled, as the motors and gearing are ashore; but this advantage is slight as compared with its accompanying disadvantages.

The " cradling " of the cables described above is a distinct advantage, for it gives increased stability to the structure laterally, and enables it to withstand wind pressure. A strong gale arose during the construction of the Runcorn Bridge, when only about one half of the stiffening girders had been built out from the towers, and were unsupported laterally by guys. It did no damage, however, the girders moving horizontally a few inches only. But for the " cradling," serious damage, and even total collapse, would no doubt have overtaken the half-finished structure.

There are several schemes on hand for erecting transporter bridges in different parts of the country, and there is no doubt that many more will be designed when people begin to appreciate their many advantages.

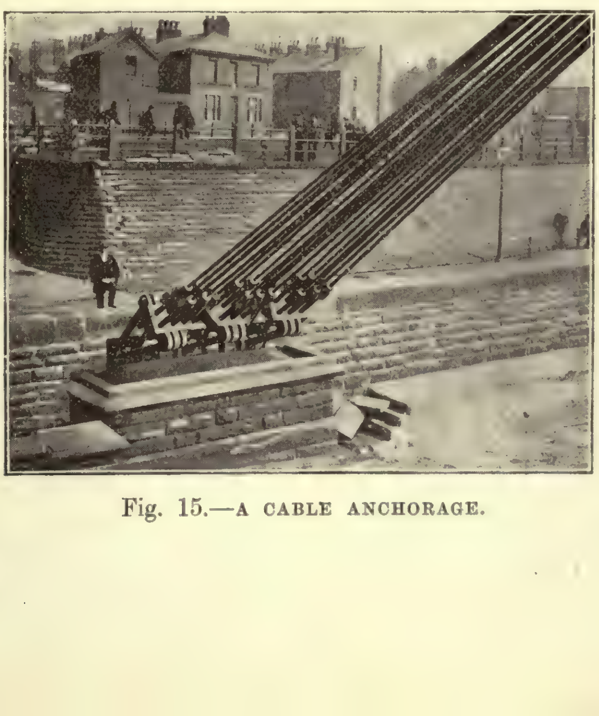


Fig. 15.—A CABLE ANCHORAGE.

THEIR DESIGN AND CONSTRUCTION.

BY HARLEY H. DALRYMPLE HAY, M.Inst.C.E.

PART II.—(*Continued from page* 240.)

Tunnels for Stations.

THE tunnels for the stations on the first section of the City and South London Railway were built of brickwork in the old-fashioned way by excavating the ground, supporting it for a short length with heavy timbering, and building the brickwork under cover of it. A great deal of the timbering was buried behind the brickwork.

Subsequently, Greathead proposed that there should be used for constructing the station tunnels large shields similar in principle to those employed for the smaller tunnels in the clay; and this practice, which is now universal, has been observed in all the London railways constructed since 1893.

Before a station tunnel can be built, it is necessary to construct what is known as a "shield chamber"—that is, a length of tunnel sufficiently large to enable the shield to be built within it. In some of the early instances this chamber was formed of brickwork, built in an excavated space supported by solid baulks of timber. During the construction of the Waterloo and City Railway, a better although a more expensive form of construction was adopted by substituting steel beams for the large timbers formerly used.

A station tunnel shield has a cutting edge at the forward end, and is divided by vertical and horizontal girders into a number of cells, rigidly connected together, from which the miners attack the face of the excavation.

Hydraulic rams placed under the floors of the cells support the face; and when the shield is being moved forward, the pressure in these rams has to be overcome by the pressure in the rams located all round the circumference of the machine, which thrust against the wooden grouting rib placed between the ram heads and the leading face of the last ring of iron segment.

The segments of a large tunnel being somewhat heavy, they are best handled by means of hydraulic erectors, which have a circular motion as well as a motion of extension or contraction.

Particulars of Station Tunnels.

The station tunnels on the Central London and on the more recent Tubes have an internal diameter of 21 feet 2½ inches, but on the Waterloo and City and the Great Northern and City Railways this is increased to 23 feet. A tunnel of 21 feet 2½ inches diameter contains a platform and one line of way. On the latest extension of the City and South London Railway, although

it has tunnels between the stations of a smaller size than any of the other Tube railways of London, the engineers have gone to the other extreme and made the station tunnels 30 feet in diameter, or larger than on any other Tube railway. This was to give an "island" platform sufficiently wide for incoming and outgoing traffic with a line on each side, as can be arranged in a tunnel of this size.

The platforms of the older Tubes were built of timber, but in the recently completed Bakerloo, Hampstead, and Piccadilly Tubes they are formed of steel joists, concrete, and granolithic paving, and are therefore fireproof.

At certain points on the several Tube railways, as well as at the terminal stations, where trains have to pass from the "up" to the "down" line for the return journey, tunnels ranging from 23 feet $2\frac{1}{2}$ inches to 25 feet in diameter have been constructed so that complete trains can cross from one line to the other. The method of constructing these is generally similar to that used for the station tunnels, the shield being of slightly larger diameter.

TUNNELLING WITH A ROTARY DIGGER.

During the construction of the Central London Railway two types of mechanical excavators were tried, with indifferent results—one in the form of a ladder dredger (Fig. 7), and the other as a rotary excavator. The latter machine had a central shaft from which extended a number of radial arms carrying cutting chisels. The shaft being rotated by electrical power, the cutting chisels remove the clay, which, on falling into the invert, is picked up by a number of buckets also fixed to the revolving arms. As the buckets reach the highest point of their journey, the clay falls out of them by gravity on to an inclined shoot, down which it slides to a conveyor placed close up to the back of the shield. The conveyor transfers the clay to trucks standing on a small wagon road at one side of the machine.

The shield is moved forward in the ordinary way by the hydraulic pressure in the rams, but a very careful manipulation is required to keep the advance properly proportioned to the rate of revolution of the cutter arms. If it be too slow, the cutters will commence to race; and, conversely, if the "feed" be too fast, the motor driving the cutters will be overloaded.

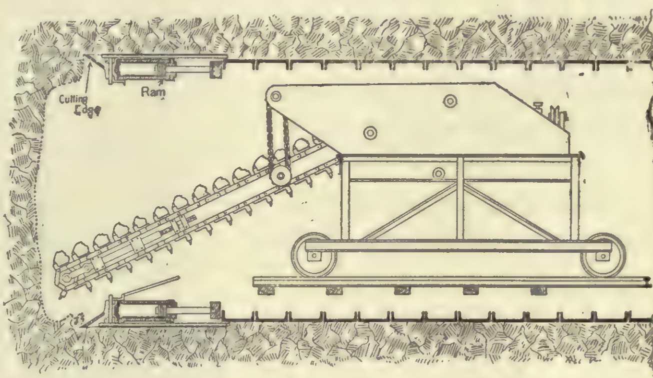


Fig. 7.—THOMPSON LADDER EXCAVATOR USED ON THE CENTRAL LONDON RAILWAY.

Principle of the Rotary Digger.

The type of rotary machine used on the Central London Railway was similar to that used recently on the Hampstead and Piccadilly Tubes, but differed in one important feature from the later machines. In the earlier machines the driving power was applied at the *axis* of the shield, whereas in the latest machines the driving power is applied near the *circumference* to a circular rack rigidly attached to and forming a part of the frame in which the radial arms and chisels are fixed. It has been fully proved by experience that this method of driving produces steadier working than is possible if the drive is transmitted through a central shaft at the axis of the shield.

The illustrations in the text (Figs. 8 and 9) are front and back views of the latest type of

shield used on the Hampstead and Piccadilly Tubes. On both these railways considerable lengths of tunnelling were executed with remarkable success by means of rotary excavating machines of the type shown. At first, especially on the Hampstead Tube, considerable difficulties occurred in driving the shields satisfactorily to line and level, and their speed was very slow. In fact, it looked at one time as if the tunnels would not be constructed either sufficiently fast or accurately to warrant the retention of the rotary type of machine. Considerable lengths of those tunnels constructed during the early period of the work had actually to be adjusted as regards both line and level before they were finally accepted from the contractor. Later on, however, after the rotary shields on the Hampstead Tube had been fitted with conveyors, their speed rose in September 1903 to sixty-eight rings as the maximum per week on any part of the work. Towards the end of November 1903 the very first attempt to drive a rotary machine round a sharp curve was made on the section of the Piccadilly Tube between Brompton Road and South Kensington, where a shield for a 12 feet 7 inches internal diameter tunnel was started round a curve of from 7 to 8 chains radius. Some little difficulty was at first experienced in steering the machine, although it was provided with graduated guide rods, etc., but ultimately it was kept well under control by observing extra care in driving.

The Digger's Efficiency.

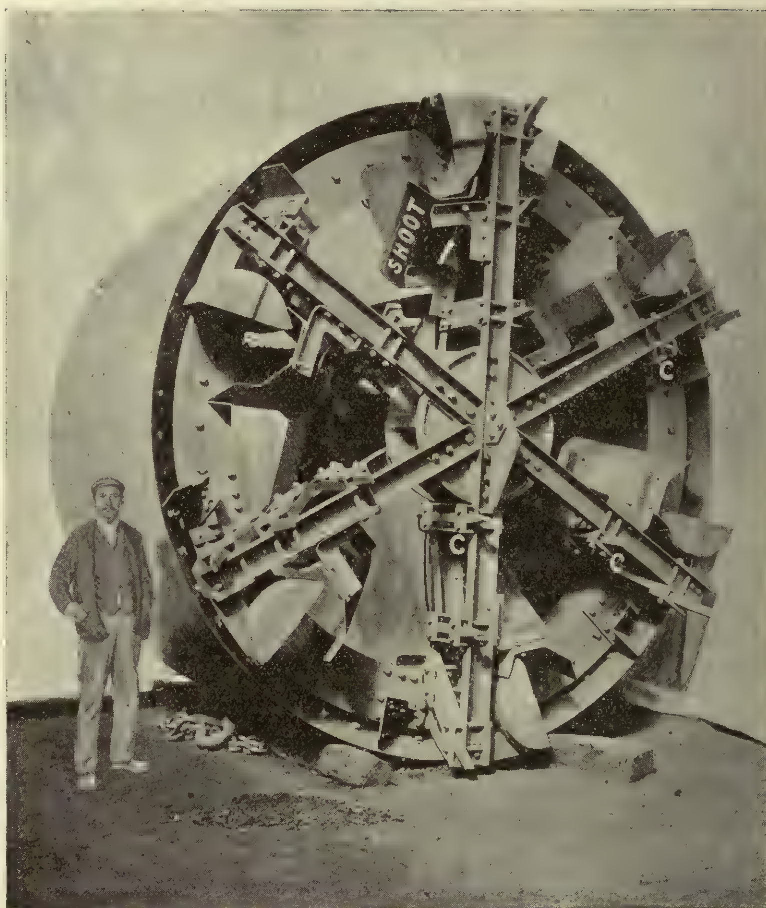


Fig. 8.—PRICE'S ROTARY DIGGER, FRONT VIEW.
B, B, buckets; C, C, chisels.

The gradual growth in the number of rings laid in a week from about forty to eighty induced fresh rivalry among the men, as every new record made was soon known at all points where the several shields were working. The machines were pushed for all they were worth. This great increase in speed naturally tried the mechanism a good deal—so much so that both the rotary machines being driven from Golder's Green towards Hampstead, after reaching the bottom of "the Avenue" by the Heath, had become so strained that it was found necessary to take them out and rebuild them entirely. The working faces were at that time over 2,000

Gradual Increase of Working Speed.

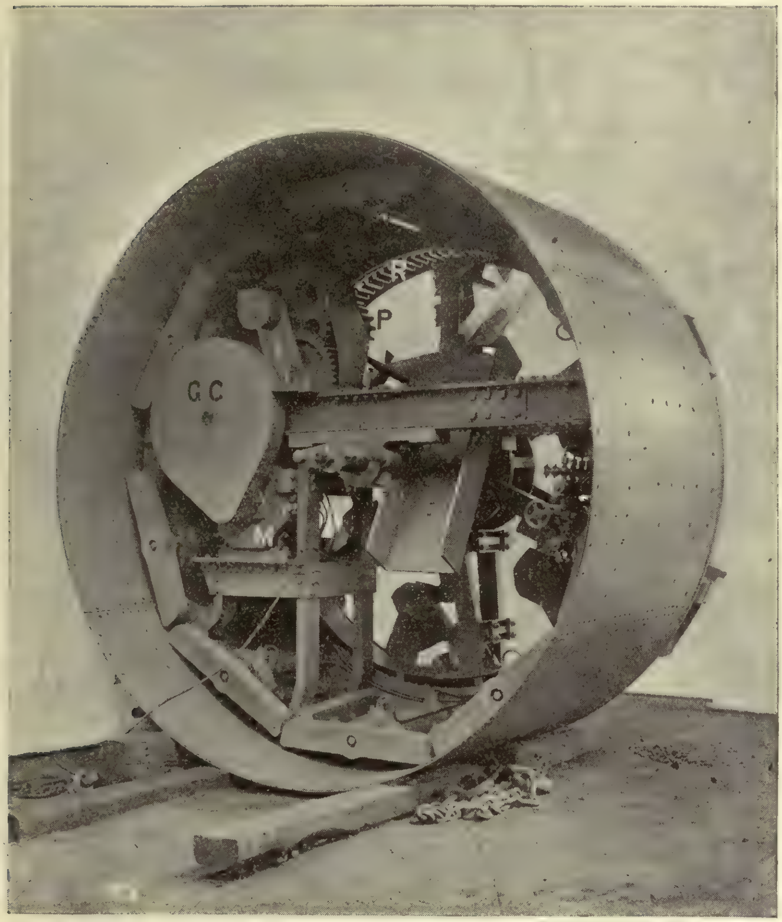


Fig. 9.—PRICE'S ROTARY DIGGER, BACK VIEW.
M, electric motor; GC, gear case; P, pinion driving R, rack.

feet from the working pit at Golder's Green, and this stoppage naturally delayed the work considerably.

Greathead and Rotary Shields compared.

Under favourable conditions the rotary progresses much faster than the Greathead shield. The superiority in this respect was very noticeable in extremely hard clay, which offered excessive resistance to the cutting edge of the Greathead, but was pared away with comparative ease by the rotary, the "feed" of which could be adjusted to suit the material exactly. On the other hand, in some kinds of ground the Greathead worked better; and on the score of accurate alignment and freedom from subsidence of tunnel lining set with its aid, the same type proved more satisfactory.

TUNNELLING IN WATER-BEARING STRATA WITH COMPRESSED AIR.

Shield-tunnelling through dry strata such as the London clay, in which by far the greater part of the Tube railways has been driven, does not in itself require the employment of compressed air to help the operations of mining at the face, although in some cases where tunnels have been driven under or close to important buildings compressed air has been used, so that the ground exposed at the working face may have the additional support due to the elastic reaction of the air.

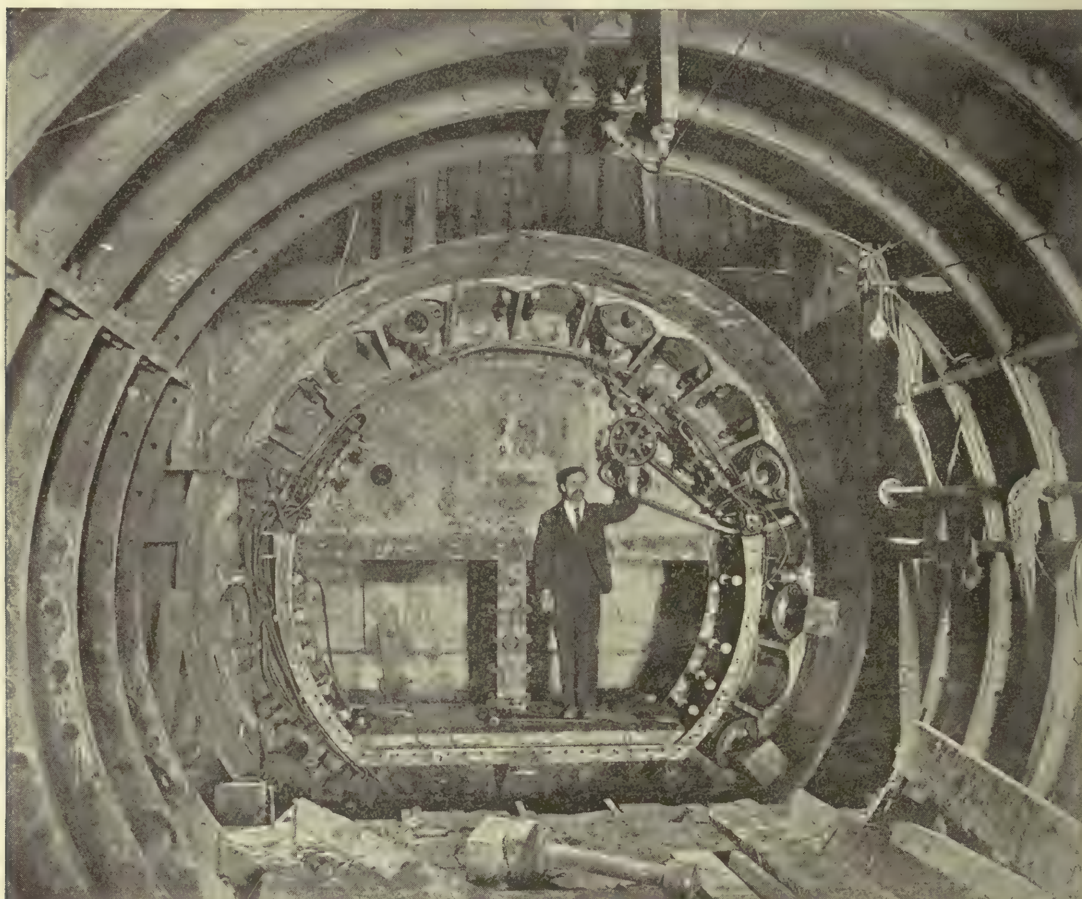
In water-bearing strata compressed air is used primarily to exclude water which otherwise would enter the workings and have to be removed by continuous pumping; and it should also be noticed that this method prevents the entrance of sand and dangerous settlements of land and buildings above.

An Admiral's Invention.

The employment of compressed air as an aid to underground mining operations and shaft-sinking was first suggested by the famous British admiral, Sir Thomas Cochrane, afterwards Lord Dundonald. In 1830 he took out a patent for an apparatus for maintaining high pressure at the working face of a tunnel. This apparatus included air-locks, through which men and materials could pass from the ordinary air into the compressed air, and *vice versâ*.

An air-lock, as now applied to tunnels, con-

sists generally of a wrought-iron or steel boiler about 5 feet 6 inches in diameter and 13 feet long, built through a brick or concrete diaphragm wall closing the tunnel at a convenient point before water is encountered. This air-lock has two doors, an outer and an inner door, both opening in the direction in which the tunnel is intended to be driven, and of which one at least is always closed.



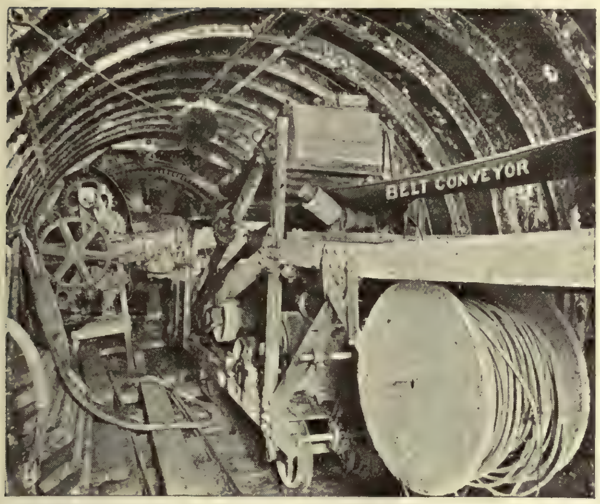
DALRYMPLE HAY'S HOODED SHIELD, AS USED ON THE BAKER STREET AND WATERLOO RAILWAY UNDER THE RIVER THAMES, WITH PORTION OF SAFETY DIAPHRAGM REMOVED.

(Photo, Bolas and Company, 5 and 7 Old Queen Street, S.W.)

Principle of the Air lock.

When compressed air is applied to the workings, the inner door — that is, that nearest to the working face— is first shut tightly against an indiarubber joint, which air cannot pass. The compressed air is furnished by a compressor or compressors at the surface, through a pipe about eight inches in diameter carried through the diaphragm wall to one side of the lock. It has a hanging valve placed at its extreme end, which projects some distance into the tunnel.

The face of the workings being impervious, the air in the tunnel between the air-lock and the working face gradually becomes compressed as the engine forces air down the shaft and through the air-delivery pipe into the tunnel. The compression is indicated in pounds per square inch by a gauge fixed on the outside of the diaphragm wall. The air pressure needed to exclude water from a heading is



CONVEYOR USED FOR DELIVERING INTO SKIPS THE SPOIL CUT AWAY BY THE ROTARY DIGGER.

(*Photo, F. Milner.*)

calculated in a rough-and-ready manner by allowing half a pound per square inch for every foot of the "head" or column of water. Thus, to exclude 30 feet of water, an air pressure of about 15 lbs. per square inch must be maintained.

We will assume that a person is about to enter the lock, in which the air stands at the same high pressure as in the part of the tunnel beyond the wall. He signals for the farther door to be shut, and then turns a valve by which the air inside the lock escapes till it attains atmospheric pressure. Then he enters, closes the valve and door carefully, and turns a cock admitting compressed air from the tunnel. At this period most novices experience a curious sensation of pressure in the ears, followed by pain and bleeding at the nose and ears, which renders a retreat advisable for the time. Discomfort is reduced by sucking a sweet to cause free salivation, and by swallowing frequently.

Passing through an Air-lock.

When the pressure inside the air-lock has risen to that in the tunnel, the inner door is pushed open easily, while the outer door is kept tightly closed by the full pressure that is acting upon it.

To come out from the workings through a lock, the procedure is reversed, the air inside being allowed to escape gradually until the outer door can be opened. Any reader who has had experience of river-locks will understand that the *principle* on which they work is similar to the compressed air-lock in all respects, the level of the water in the one case corresponding to the air pressure in the other. Before the passenger can enter or leave a lock, the air or water conditions must be the same inside the lock and on the side from which or to which he wishes to go.

Tunnelling and shaft-sinking with the help of compressed air differ somewhat. For sinking a shaft it generally suffices to provide as a maximum air pressure that corresponding to the maximum head of water to be dealt with, because, the base of the shaft being horizontal, the water pressure will be the same over the whole area of the base of the shaft—assuming the simple case in which the strata pierced by the shaft are uniform in character.

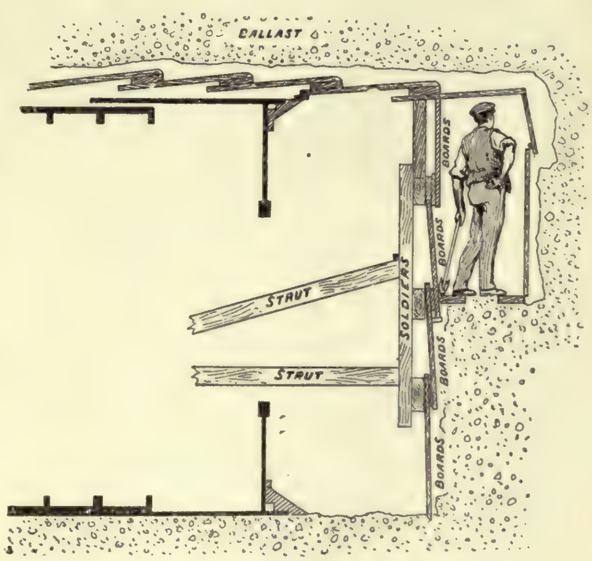


Fig. 10.—THE ASSISTED SHIELD METHOD OF TUNNELLING THROUGH WATER-LOGGED GROUND.

The solid black lines indicate shield and tunnel lining in section.

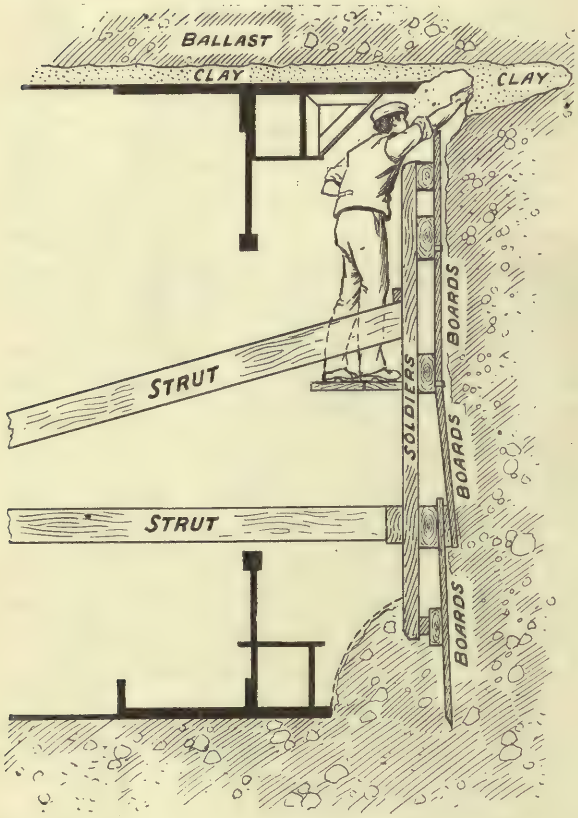


Fig. 11.—THE HOODED SHIELD AND CLAY-POCKET SYSTEM OF TUNNELLING THROUGH WATER-BEARING STRATA.

But in the case of a tunnel it is obvious that the water pressure at the bottom is greater than that at the top of the tunnel. As, however, the pressure of the air must be sufficient to balance the water pressure at the bottom, there is consequently a tendency for a large amount of air to escape at the upper part of the face, where, if the nature of the material is the same throughout its depth, as it is assumed to be in this hypothetical case, it would naturally take place.

A Difficulty in Tunnelling.

In practice, of course, the nature of the material varies greatly. In fact, under the Clyde, during the construction of some tunnels in Glasgow, it was found that a smaller pressure was required at time of high-water, when the head was greatest, than at times of low-water, the explanation being that the additional weight of water so consolidated the sand and mud through which the tunnel was being driven as to negative largely the effect of the increased head. The air losses through the face were correspondingly reduced.

A Curious Fact.

CIRCUMVENTING DIFFICULTIES.

Where the ground is so loose that it will not stand of itself, special measures are required to prevent its falling in at the working face and subsiding on to the tunnel lining behind the shield when the latter is advanced, and before the annular space left by the skin of the shield has been filled with grout.

When water was encountered on the City and South London Railway, Greathead adopted what he termed his "assisted shield system" of operations. He drove a timbered heading at the roof of the tunnel, a short distance in advance of the shield. This heading was roofed in with poling boards and grout, under cover of which the face could be excavated laterally and downwards, the space so excavated being supported by boards resting at one end on the shield, and at the other end on vertical timbers placed against the face of the excavation. The excavation of a "length" being complete, the face timbering had to be secured independently of the shield before the latter could be moved forward to permit the insertion of another ring of lining. Two vertical timbers, called "soldiers," were laid against the boards of the face, and held tightly in position by struts projecting through the shield and wedged against a transverse beam jammed between the segments of the third ring from the end. (See Fig. 10.)

The "Assisted Shield" Method of Tunnelling.

A circular timber grouting-rib was now inserted between the heads of the hydraulic rams and the leading face of the tunnel ring,

and made tight by ramming clay into any cracks between it and the skin of the shield. The grout was then forced into the cavity through holes made for the purpose in the segments.

This system of tunnelling required the formation of a timbered "length" practically all round the shield before the apparatus could be moved forward; and the poling boards had to be left permanently between the iron lining and the ground. During the construction of the Waterloo and City Tube a novel method of tunnelling through water-logged strata was tried. This, known as the "hooded shield and clay-pocket system," consists of first excavating a series of holes, 12 inches high and wide and 23 inches long, in advance of the cutting edge, and filling them with puddle clay. (Fig. 11.) In this manner three-quarters of an annular ring of clay was formed. Meanwhile an excavation had been made for the lowest quarter of the shield to advance into. The clay was penetrated easily by the cutting edge. Be it noted that a sufficient quantity of clay was put into the pockets to ensure a layer two inches thick being left between the shield and the ground. When the shield advanced, the ground at the tail end was deprived of the support afforded by the shield; but it would not fall in, as the air-pressure in the tunnel, acting against the impervious clay, afforded sufficient support.

The "Clay-Pocket" System.

VIEW SHOWING EFFECTS IN THE THAMES OF A "BLOW-OUT" OF COMPRESSED AIR FROM TUNNEL WORKINGS THROUGH THE BED OF THE RIVER. (*Photo, F. Milner.*)

In this manner the necessary grouting space outside the iron lining was maintained. This method was used with great success in both tunnels of the Bakerloo Railway under the Thames at Charing Cross. It enabled five feet of tunnel to be put in every twenty-four hours, although the material pierced was open gravel permeated by water having a 70-foot "head"—30 lbs. to the square inch.

We may close this section by narrating a curious episode. While one of these tunnels was being driven, a competitor for "Doggett's Coat and Badge," the celebrated Thames watermen's race, got into difficulties in a whirl of water caused by a "blow-out" of air from the tunnel, and, as he maintained, lost the race on that account. (An illustration of the effect of a "blow-out" is given on p. 307.)

WORKING IN A HOODED SHIELD. *(Photo, Woodburytype Permanent Photographic Printing Co.)*

ERECTING IRON LINING IN SMALL TUNNELS.

The cast-iron lining of running tunnels consists of a series of rings, each 20 inches long, and composed of six segments and a key-piece at the top. The segments of a ring and adjacent rings are joined together by bolts.

One of the most interesting things to watch during the actual construction of a shield-driven tunnel is the erection of this permanent iron lining.

The operation is performed entirely by manual labour in the case of small tunnels, as

the space is so limited that it is not possible to design a segment-erecting machine sufficiently compact not to interfere with other operations at the face.

The lining is sent to the working face on small trolleys, three segments as a rule being stacked together at one time, convex side downwards. On arrival at the face, at the words "Say when" from the leader, four men lift a segment from the trolley with iron bars inserted through the end holes in the curved flanges, carry it some four paces, and deposit it on the stage forming the working floor of the shield.

Placing a Segment.

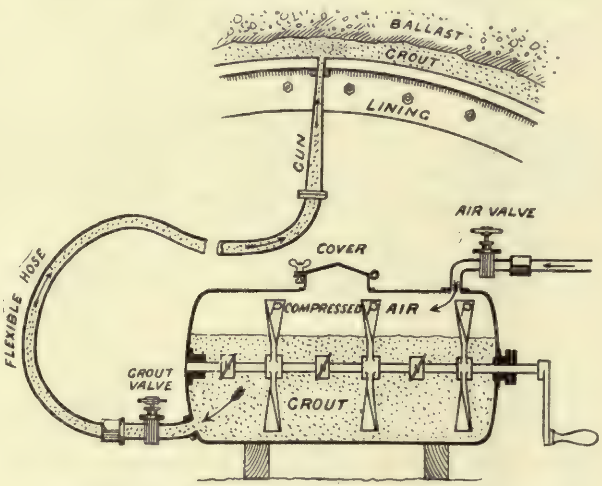
It is then turned *concave* side downwards, is raised by six men and put over on to, say, the left side of the floor, from which it immediately slides down the side of the shield by its own weight to the lowest part of the invert.

The floor planks are then removed, to give access to the bottom. A labourer at once descends into the bottom of the shield and starts bolting up this segment to the last ring. The right-hand invert segment having been similarly dealt with, the floor planks are restored to their normal position, and the two side segments are put into place and bolted up. A temporary timber stage is then formed across the tunnel, and the two roof segments are lifted into position. Finally, the key-piece is driven in from below, and the ring is complete.

The whole operation of erecting a ring complete takes twenty minutes when all goes well. The men, working by piecework as a rule, lose no time. Each man of the gang has his allotted duty. Some fetch, others tighten up bolts, while the bulk of the gang is engaged in the more arduous task of getting the segments into their final positions.

In order to hasten the work to the utmost during the erection of the ring, a couple of men are told off to pick down the clay in the face and restart the excavation of a new "length." When the erection of the ring is finished, two miners go into the heading again and proceed with its further construction.

The grouting up of the ring to which the



SECTIONAL DIAGRAM OF A "GROUTING" APPARATUS, SHOWING HOW THE GROUT IS FORCED BETWEEN THE TUNNEL LINING AND THE GROUND.

new ring has been bolted is then proceeded with, the operation taking about twenty minutes to complete. The grout itself sets very hard in a short time, and so gives substantial support to the ground by completely filling up the annular space left between the iron lining and the ground.

Grouting a Ring.

METHODS OF GETTING RID OF WATER FROM COMPLETED TUNNELS.

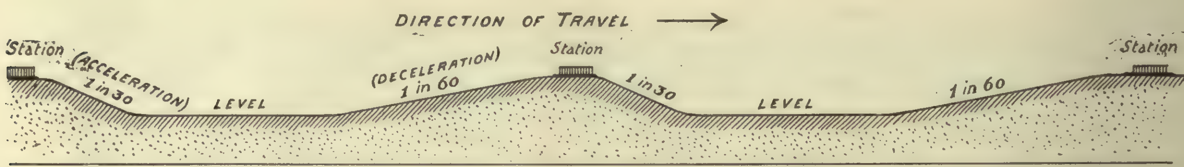
It is always necessary, in those portions of a Tube railway which have been constructed in water-bearing strata, to provide for the permanent removal of water which leaks into the tunnels despite the great care exercised in making the joints and bolt-holes watertight.

The usual practice is to provide a small length of tunnel at a slightly lower level than, and at the lowest part of, the works, and to install therein duplicate electrically driven

pumps to remove the water from the invert of the small tunnel.

In one case, where the works were constructed in fine running sand under 15 to 20 lbs. per square inch compressed air, a somewhat novel method of getting rid of the water was carried out. In this instance it was known that at a depth of some 200 feet below the tunnels water-bearing flints would be encountered in the chalk, and as the water-level in the chalk stood at a level several feet below the tubes, it was thought that the water which came by leakage into the tubes would itself drain away by gravity down a bore-hole; so one was made.

This is rather an "upside-down way" of doing things, as it is usual to put down borings specifically for the purpose of obtaining water *from* the chalk, and not for draining away water which it is inconvenient to deal with otherwise. However, in this case complete success attended the experiment, and the railway company now do no pumping whatever, as the water passes down the bore-hole and mingles in the chalk with the great body of water from which Londoners obtain so large a proportion of their supply.

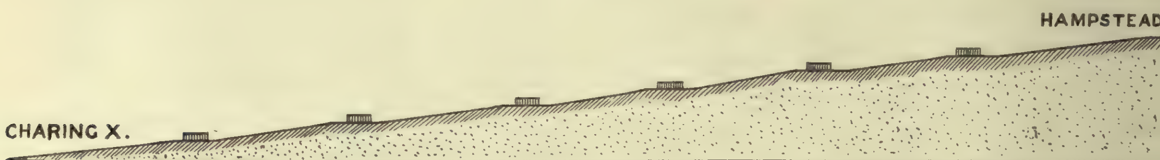


THE "DIPPING GRADIENT" SYSTEM (GRADES GREATLY EXAGGERATED) USED ON SOME OF THE TUBE RAILWAYS.

GRADIENTS.

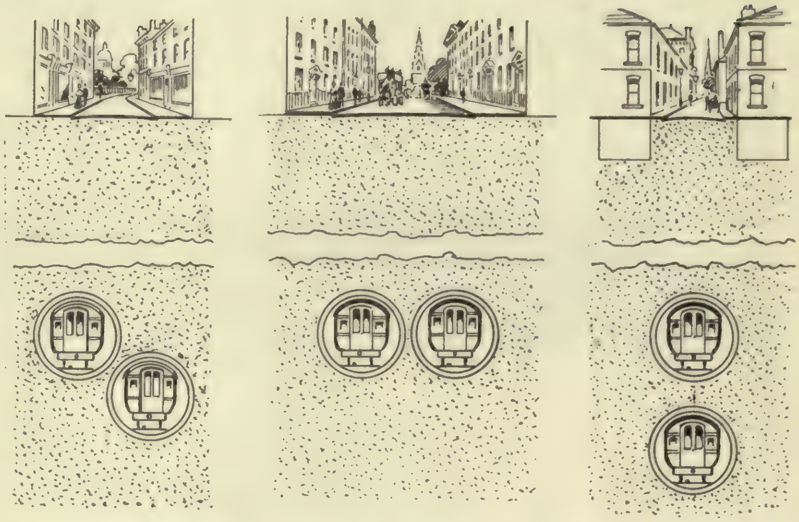
A peculiar feature in connection with the London Tube railways, and one that tends to great economy in the cost of operation, is the method used, where possible, of so grading the tubes that between stations there may be a dip or depression, each station being, as it were, on a summit. To show that this is nothing new, however, it may be mentioned that so long ago as the year 1833 a model of a spring locomotive and a short length of track with gradients dipping between the stations was made by some persons interested in railway construction; and that a large number of the shareholders of the London and Birmingham Railway petitioned the directors to stop the construction of that railway, and also to proceed with the section between Liverpool and Birmingham on the principle of dipping gradients. They maintained that the experimental spring locomotive had demonstrated that, as compared with a level line, a railway with dipping gradients enabled the journey to be done in two-thirds of the time for the same expenditure of power.

"Dipping" Gradients.



UPHILL GRADE, WITH LEVELS AT STATIONS, AS ON CHARING CROSS AND HAMPSTEAD RAILWAY.

This, of course, is true only if there be a station at each summit at which the train has to stop; so nothing came of the proposal until Greathead applied this principle, as far as possible, on the original sections of the City and South London Railway. In all subsequent Tube lines, the Central London Railway particularly, this principle has been observed where practicable.



VARIOUS RELATIVE POSITIONS OF THE TWO RUNNING TUNNELS OF A TUBE RAILWAY.
The disposition depends largely on the breadth of the thoroughfare overhead.

Gradients on the Tubes.

A train on quitting a station at once strikes a downhill grade of 1 in 30, extending for such a distance that, assuming the motors to be taking current until the train commences to descend the 1 in 30 grade, the speed at the bottom of the incline under gravity alone will be about 25 miles per hour. The train then proceeds along a level stretch of line, using very little, if any, current, and so continues to run at a high rate of speed to within a short distance of the next station, when an up-hill grade of 1 in 60 against the load acts as a brake to the train and rapidly checks it. The air-brakes have to do much less work than on an ordinary railway.

This is not only theoretically the proper way for a train to run a section, but is also practically the best, as it enables a maximum average speed to be attained at a minimum cost of energy and braking.

The two tunnels of a Tube railway, although generally placed side by side "spectacle fashion," are often placed one above the other. We may mention one notable instance.

On the original section of the City and South London Railway, where the tunnels pass under Swan Lane, on the northern side of the river near London Bridge, the width of the lane being only just sufficient to admit of one tunnel passing along it without encroaching on the property on either side, the tunnels were placed one above the other.

In such a case, the precaution is generally taken of constructing the lower tunnel first. If the upper one were completed first, there would be considerable risk of its subsiding on to the lower while that was being driven.

Steep Gradients.

The section of Tube railway which has the steepest gradients against the load of any in London is that of the Piccadilly Tube, between Earl's Court and Baron's Court, where the grade is 1 in 50 for 2,213 feet; but the Hampstead Tube has a longer grade of 1 in 60 for 4,333 feet between Hampstead and North End.

The Hampstead Tube has also the deepest lift shafts of any line in London, those at Heath Street Station sinking 181 feet below the street. The greatest depth of the tunnel below the surface is near the White Stone Pond on the same railway, where the rails are 250 feet below the Heath.

THE DEVELOPMENT OF THE SHIP

BY ALBERT G. HOOD,

Editor of "The Shipbuilder."

This is the first of a Series of very interesting Articles on the Development, Design, Construction, and Propulsive Machinery of Steamships.

Birth of the Shipbuilding Industry.

SINCE the use of contrivances to assist man to float must have commenced almost as soon as the world began, one must have recourse to the tombs and monuments of ancient Egypt in order to trace the birth of the shipbuilding industry. Ships, as distinguished from the raft or the "dug-out," by which we mean a tree trunk hollowed out by man, were constructed in Egypt long before the advent of the Pyramid builders; and thus the land of the Pharaohs—so far, at least, as research up to the present has revealed—must be credited with being the oldest shipbuilding country in the world. According to Sir George Holmes, in his fascinating book *Ancient and Modern Ships*, it may be safely inferred that ships were used by the Egyptians sixty-seven centuries ago. The late Mr. Villiers Stuart, in his work *Nile Gleanings*, reproduced the oldest authentic picture of an Egyptian vessel, copied from a tomb. This ship, which was in use on the Nile about six thousand three hundred years ago, or fifteen centuries before the date commonly accepted for Noah's ark, must have had a length of at least 56 feet, with a beam of about 7 feet, and was propelled by oars, or rather paddles, and sails. Rameses II. carried on wars by sea, and there are in existence illustrations of the battleships of Rameses III. (1200 B.C.), in which the rowers were protected from the enemy's missiles by strong bulwarks, while the commander directed operations from a kind of crow's nest at the masthead, the sides of which afforded him a certain amount of cover. Thus we have the origin of the heavily armoured battleship of the present day, which on going into action is controlled from a conning tower. It would be an interesting study to trace the shipbuilding industry from the Egyptians to the Greeks, the Phœnicians, and the Romans, but it hardly comes within the province of this article. It may be mentioned, however, that so recently as 1905 the late Mr. Wigham Richardson, the eminent Tyne shipbuilder, constructed a model of the trireme, or war-

Note.—*The heading shows the "Lusitania" compared with the famous Cunard Boat-Train.*

galley, as used by the ancient Greeks, and contributed to the shipbuilding press an article in which the fallacy of many long-prevailing ideas concerning the construction of this type of ship was clearly demonstrated.

The honour of designing and building the first ships worthy of the name in Britain undoubtedly belongs to Alfred the Great. His ships, according to historians, were longer and had better sailing qualities, including more "freeboard" (height of side out of the water), than those belonging to his enemies, the Danes, whom he defeated in several naval encounters. Perhaps one of the most important links between ancient and mediæval shipbuilding which has been preserved for us was the Viking ship discovered near Sandefjord in 1880. This vessel, which was of oak, clinker-built, and 78 feet long, showed that her builders were no novices in ship construction, and that they possessed more than an elementary knowledge of the problems of ship resistance.

Viking Ship.

THE FULL SIZED MODEL OF COLUMBUS'S FLAGSHIP, THE "SANTA MARIA," ON HER WAY TO THE CHICAGO EXPOSITION.

(*Photo, Rischgitz Collection.*)

Columbus's Flagship.

The fleet with which Christopher Columbus sailed across the then unknown and perilous Atlantic Ocean in 1492 in order to discover a new route to the Indies, consisted of three vessels, the *Santa Maria* (flagship), the *Pinta*, and the *Niña*. All three were small craft even for that period, as it should be borne in mind that for a number of years previous to the departure of the discoverer on his memorable voyage Spain possessed a fleet of ships of considerably larger tonnage. The Spaniards probably regarded Columbus's voyage as far too hazardous for them to risk their larger and more costly vessels. It will be within the recollection of some of our readers that the *Santa Maria*, the largest of the little fleet, was reconstructed in Spain in 1892, and sailed over the Atlantic for the Chicago Exposition of 1893. As reproduced, the ship had

THE FAMOUS "GREAT HARRY" OF HENRY THE EIGHTH'S TIME. FIRST ENGLISH THREE-DECKER.

(From an original drawing by Anthony in the Pepysian Library, Magdalene College, Cambridge. Photo, Rischgitz Collection.)

a length of between 60 and 70 feet at the keel, an overall length of over 128 feet, and when fully laden she displaced 233 tons of water. She was fitted with three masts, the fore and main masts being square-rigged. Like practically all the ships built in the latter half of the fifteenth century, the *Santa Maria* had a huge forecastle forward and a raised poop aft, structures which doubtless contributed not a little to the bad sailing qualities of the ship; for it is recorded that the Spanish crew who navigated the duplicate vessel across the Atlantic in 1893, when the same course was taken as sailed by the original ship, found that she rolled terribly.

Application of Steam to Marine Propulsion.

The application of steam to marine propulsion did not take practical shape until 1788 or 1789. In the latter year Messrs. Miller and Symington successfully tried a steamboat on the Forth and Clyde Canal. The *Charlotte Dundas*, a steam-tug, followed in 1802. The propelling machinery of this vessel consisted of a horizontal direct-acting engine—the first ever constructed—driving a stern wheel. In 1807 Fulton's *Clermont*, a ship 133 feet long, with engines supplied by Messrs. Boulton and Watt of Birmingham, England, commenced running successfully on the Hudson River between New York and Albany. Five years later, or in 1812, the *Comet*, a side-wheel boat, began to ply regularly on the Clyde between Glasgow and Greenock, her speed being about five miles an hour.

Three hundred and twenty-seven years elapsed after Columbus's first voyage to America before the first steam-propelled vessel

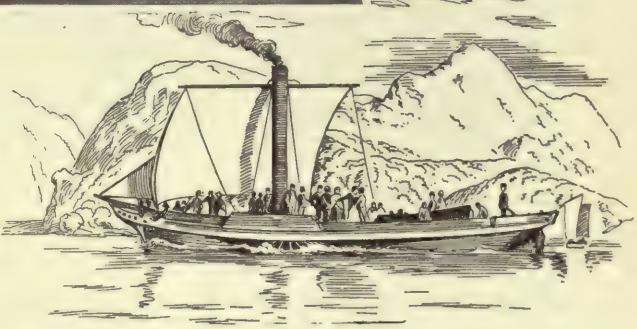
THE ILL-FATED "ROYAL GEORGE," CARRYING A HUNDRED GUNS. LAUNCHED 1756.

(Photo, Rischgitz Collection.)

THE "CLERMONT." BUILT BY ROBERT FULTON, 1807.

THE "CHARLOTTE DUNDAS," THE FIRST STEAMER IN THE UNITED KINGDOM. EMPLOYED IN TOWING BOATS ON THE FORTH AND CLYDE CANAL. BUILT, 1801; ENGINE BY WILLIAM SYMINGTON.

(*These are sketched and copied from Prints in the Rischgitz Collection.*)



THE "COMET," 1812. FIRST PASSENGER STEAMBOAT IN THE UNITED KINGDOM.

Speed, 7½ miles an hour.

crossed the Atlantic. The *Savannah*, a paddle steamer of 300 tons, arrived at Liverpool from Savannah, Georgia, in June 1819. The voyage was made mainly under sail, however, as during the twenty-five days occupied by the trip steam was used for only eighty hours, and her fuel was exhausted before Liverpool was reached. Scientists and naval men alike appear at this time to have been practically unanimous in the opinion that no vessel could ever be constructed capable of carrying sufficient fuel to enable her to steam right across the Atlantic, and the performance of the *Savannah* was merely regarded as a novel experiment, without any real significance. Yet the practical utilization of the steamship for oversea traffic was soon to be accomplished. In 1840 the *Britannia*, a wooden paddle steamer, 207 feet long, inaugurated the Cunard Company's Atlantic service. Her average speed was about 8½ knots per hour, and she used to accomplish the journey from Liverpool to Boston in something over fourteen days.

Early Atlantic Steamships.

But although the marine steam-engine, as already explained, was no longer a dream at the beginning of the nineteenth century, the glory of the sailing ship did not begin to wane until about 1850. Indeed, so late as the year 1870 the bulk of the world's merchandise was carried oversea in wooden sailing ships. To America must be accorded much of the credit for improvements in mercantile sailing ships between 1800 and 1850. Wooden sailing ships were still being launched from American yards in consider-

Decline of the Sailing Ship.

able numbers, a fact which was due largely to the country's immense resources of timber. For some time after 1840, when steamers commenced to cross the Atlantic regularly, much faster sailing packets than had previously been built continued to compete for both the passenger and cargo trade between the Old and New Worlds; but gradually only the longer sea journeys, such as between the British Isles and China or Australia, were left open to the sailing ship. British shipbuilders at length began to compete successfully with the American builders of sailing vessels, and about 1855 the English-built clippers began to race the American-built ships in the run from China to this country with the early season's teas. The time made by some of these fine clippers was remarkable, and the public interest taken at this time in their performances is hardly exceeded by that evinced in the recent record-breaking by the great Cunarders in the Atlantic.

Wood, Composite, and Iron Ships.

It is interesting to conjecture whether North America would have maintained her position as a centre of the shipbuilding industry if wood had continued to be the principal material used in the construction of ships. The high cost and growing scarcity of suitable timber, however, and the structural difficulties encountered in building wooden ships nearly 300 feet long stout enough for heavy ocean work, caused the naval architect to search for another building material. Iron began to be introduced in the construction of large wooden sailing ships and steamers for stiffening and strengthening the hulls, the vessels so built being known as "composite" ships; and this practice was in vogue for a good many years. The use of iron as a recognized ship material—that is, for the whole of the hull—is said to date from about the year 1818, but it was many years later before it became general for sea-going vessels.

In 1839 the construction of a remarkable steamship, afterwards to be known as the *Great Britain*, was commenced at Bristol, to the designs of Mr. I. K. Brunel.

The "Great Britain" Screw Steamship.

This ship has special claims on our attention as one of the first iron steamships and the pioneer screw-propelled vessel built for the Atlantic trade, only paddle-wheel ships having been employed previously between Britain and America. Her dimensions at that time were considered marvellous. She had a length between perpendiculars of 289 feet, an extreme breadth of 50 feet, and at her load draught she displaced 3,618 tons. Like all early ocean-going steamers she had considerable sail power. When she left her builders' yard she was fitted with six masts, and her total spread of canvas was 1,700 square yards—more than one-third of an acre! The average speed of the *Great Britain* on her first voyage was 9 knots. In this vessel were anticipated, to a remarkable extent, the principles of ship construction in favour at the present day, for in her was exemplified a strongly-built and well-shaped iron hull without external keel, a "balanced" rudder, and a double bottom.

The year 1858 saw the launch on the Thames, after many attempts, of the *Great Eastern*, the most remarkable *iron* structure the world has ever seen.

The "Great Eastern."

Mr. I. K. Brunel, the designer of the *Great Britain*, conceived the idea of building this mammoth vessel. Designed to make the voyage between Britain and Australia without calling anywhere *en route* for the purpose of coaling, she was expected to attain high speed, thanks to her enormous length, and to be financially successful owing to her immense carrying power. Eventually the building of the ship was entrusted to Messrs. John Scott Russell and Company of Millwall. Mr. Brunel watched the construction on behalf of the owners (the Eastern Steam Navigation Company), and he and Mr.

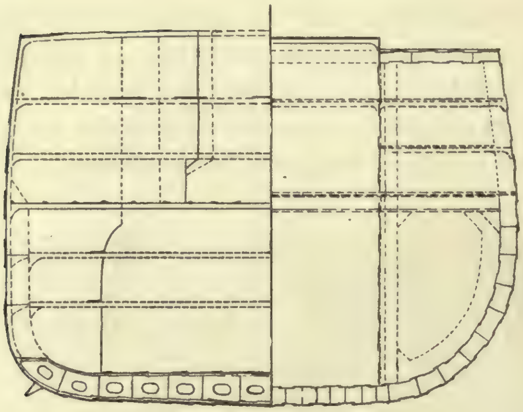
Scott Russell were jointly responsible for the design. The vessel was propelled by both paddle and single-screw engines, and the following table gives her leading particulars as constructed :—

Length between perpendiculars	680 feet.
Length at upper deck	692 feet.
Extreme breadth of hull	83 feet.
Breadth over paddle-boxes	120 feet.
Depth from upper deck to keel	58 feet.
Loaded draught of water	30 feet.
Gross tonnage	18,914 tons.
Weight of iron used in construction	10,000 tons.
Coal and cargo carried	18,000 tons.
Nominal horse-power of paddle engines	1,000.
Nominal horse-power of screw engines	1,600.
Accommodation for first-class passengers	800
,, second-class passengers	2,000
,, third-class passengers	1,200
,, crew	400
Total number of passengers and crew	4,400

The construction of such a vessel naturally involved many departures from the principles of construction then in operation. We give an outline cross-section showing the principal structural features of the *Great Eastern*, and, by way of comparison, a section of the Cunard liner *Lusitania* has been drawn alongside. In the former vessel Mr. Scott Russell's system of longitudinal framing was adopted—that is, the frames or ribs extended from end to end of the ship, and not from the keel to the deck, or transversely, as in the method of construction now almost universally followed. Numerous iron bulkheads or partitions, both transverse and longitudinal, were fitted, serving to strengthen the hull and to divide it into separate water-tight compartments. The uppermost deck, the bottom, and a large portion of the sides of the ship were constructed on the cellular principle, the inner bottom and inner sides constituting what was practically

THE "GREAT EASTERN" (1858) IN THE THAMES.

(Reproduced from the "Illustrated London News," 1859.)



MIDSHIP SECTIONS OF THE "LUSITANIA" (TO THE LEFT) AND "GREAT EASTERN" COMPARED.

a second hull. The longitudinal bulkheads were carried right up to the upper deck, thus contributing largely to the longitudinal strength of the ship. The inner skin, while giving additional structural strength, acted as a safeguard in the event of collision or grounding; and the space between the outer and inner skin was utilized for carrying an immense quantity of water ballast. The transverse strength was supplemented by the bulkheads carried in that direction, and there was no transverse framing, as in present-day steamers. Experience at sea proved that structurally the *Great Eastern* was an unqualified success, for she never showed any signs of weakness. On her preliminary sea trip the highest speed attained was 15 knots. Although a triumph of shipbuilding skill, the vessel was a great failure commercially. She was never placed in the trade for which she was designed, but commenced running in the Atlantic, for which she was wholly unsuited. In 1865 and 1866 she performed good service in laying two of the Atlantic telegraph cables, but in 1888 she was sold to be broken up. It is a splendid tribute to the genius of the two famous engineers who were responsible for her design that even now, after the lapse of half a century, our naval architects look to the *Great Eastern* for inspiration and guidance in ship design.

From the building of the *Great Eastern* to the present time the development of the steamship, in regard to both size and speed, has been steady and continuous; but in the space at our disposal it is impossible to make more than a brief reference to improvements in shipbuilding methods, and to the notable ships of the past fifty years. From about the year 1870 iron screw steamers began to supersede sailing ships in very many of the ocean trades of the world, a result due largely to the rapid strides made in marine engineering. The increased use of water ballast in steamers directed

Developments during the Past Fifty Years.

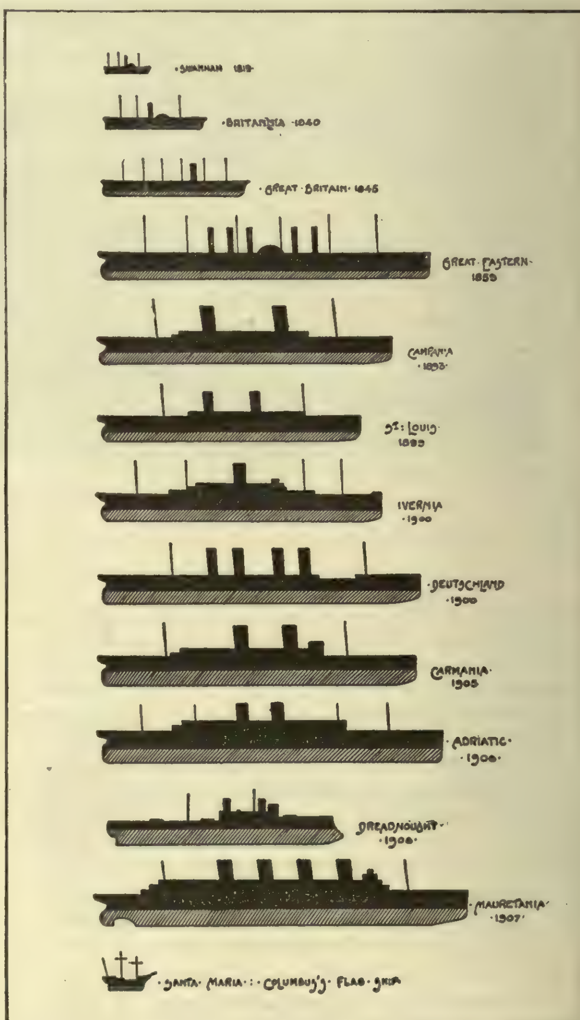


DIAGRAM SHOWING DEVELOPMENT IN THE SIZE OF STEAMSHIPS DURING THE PERIOD 1819–1907.

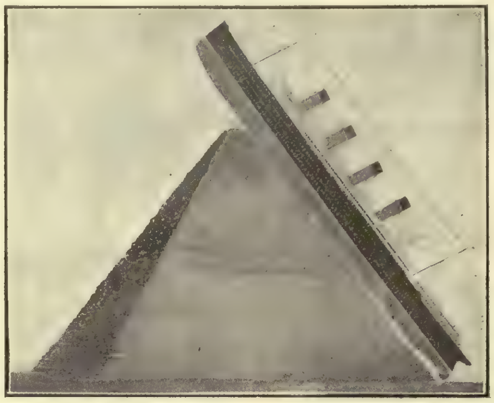
attention to the necessity for constructing ballast tanks as an integral portion of a ship's structure; and in 1876, Mr. G. B. Hunter (then of Sunderland, and now of Wallsend-on-Tyne) introduced in the bottom of the *Fenton*, a small iron steamer, the combination of transverse framing with cellular arrangement of floors and keelsons for carrying water ballast, now almost universally adopted.

Steel, as a substitute for iron, was first used for ship construction between the years 1873 and 1878. The new material was introduced into portions of the structure of French warships in 1873. In the same year the British Government ordered two dispatch vessels, the *Iris* and *Mercury*, to be built entirely of steel, and the use of this material soon became general in the construction of ships for the Royal Navy. In 1878 several steel merchant vessels, both sail and steam, were built in this country, and since that time practically all large vessels have been constructed of steel.

Increase in Size and Speed.

Since the advent of the steamship, the largest vessels afloat have been employed in the mail and passenger trade between Great Britain, Germany, or France and North America. The diagram of notable Atlantic vessels which we give (page 318) therefore illustrates the development in the size of steamships. To make this diagram more interesting and comprehensive, an outline of His Majesty's battleship *Dreadnought* has been added.

As to the increase in speed of steamers, it was natural that the problems connected with the attainment of high speed should be first solved in the case of cross-channel vessels designed for comparatively short sea passages. Notable examples of successful steamers of this type were the *Connaught*, *Ulster*, *Munster*, and *Leinster*, built in 1860, for the conveyance of passengers and mails between Kingstown and Holyhead. These vessels, with their paddle engines, attained a speed of over 20 knots on trial. The development in speed of ocean-going vessels from the year in which the *Great Eastern* was completed (1859) to the present is shown in the following list of notable transatlantic steamers:—



THE "MAURETANIA" COMPARED WITH THE GREAT PYRAMID OF CHEOPS.

Name of Steamer and Line.	Date Built.	Speed at Sea.
Scotia (Cunard)	1862	14¼ knots.
Adriatic (White Star)	1872	14¾ knots.
Britannic (White Star)	1874	15 to 16 knots.
Arizona (Guion)	1879	17 knots.
City of Rome (Anchor)	1881	17½ knots.
Umbria and *Etruria* (Cunard)	1884	18½ to 19½ knots
City of Paris (Inman)	1888	19 knots.
Majestic and *Teutonic* (White Star)	1889	19 knots.
Campania and *Lucania* (Cunard)	1893	22 knots.
St. Louis and *St. Paul* (International)	1895	21 knots.
Kaiser Wilhelm der Grosse (Norddeutscher Lloyd)	1898	22½ knots.
Oceanic (White Star)	1899	20½ knots.
Deutschland (Hamburg-Amerika)	1900	23¼ knots.
Kronprinz Wilhelm (Norddeutscher Lloyd)	1901	23¼ knots.
Kaiser Wilhelm II. (Norddeutscher Lloyd)	1904	23½ knots.
La Provence (Générale Transatlantique)	1905	22 knots.
Kronprinzessin Cecilie (Norddeutscher Lloyd)	1906	23½ knots.
Lusitania and *Mauretania* (Cunard)	1907	25 knots.

Will Steamships continue to grow in Size and Speed?

As to the future, the question is often asked, Will steamships continue to grow in size and speed? The problem is an interesting one. To deal with the last part of the question first, it may be said that the 25 knots speed of the Cunard liners *Lusitania* and *Mauretania* probably represents the maximum that will be attempted in mercantile vessels for some years to come, unless some revolutionary change be made in the mode of propulsion. Limitation of speed, however, is mainly the

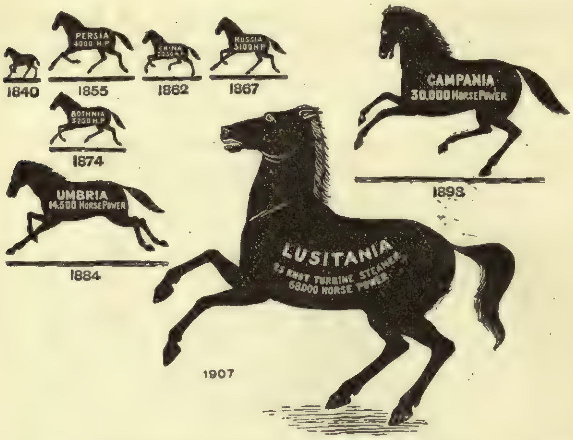
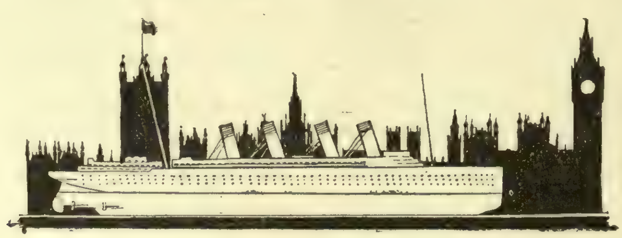


DIAGRAM SHOWING INCREASE IN THE HORSE-POWER OF THE CUNARD LINERS' ENGINES DURING THE PERIOD 1840–1907.

result of commercial considerations, as to maintain a higher speed than 25 knots over an ocean voyage would involve enormous outlay, owing to the great size of vessel and the heavy consumption of fuel required. On the other hand, such considerations do not—at all events not to the same extent—affect warships, and it is likely that the speed of the smaller units of the world's fighting fleets (torpedo-boat destroyers, etc.), and possibly also of battleships and armoured cruisers, will be appreciably increased during the next few years.

On the equally important question of ships of larger dimensions, it may be remarked that the tendency to increase in size has, for some years past, been strong and continuous. The world has not ceased to marvel at the huge proportions of the two latest Cunarders; but already two vessels of greater size, although of much less speed, are under construction at Belfast for the White Star Line. These two liners will each be well over 800 feet in length, and their tonnage will approach 43,000. There are really no structural difficulties which could not be surmounted in building steamers 1,000 feet long, and many of the great shipbuilding firms have laid out building berths capable of dealing with ships of that size. Experience proves that the power required to drive a ton of ship's displacement (ship and cargo) at a given speed diminishes, and the working expenses per ton become less all round, with increase of size. Naturally, docking and harbour facilities will be an important factor in the shipbuilding programme of the future. There are at present very few dry docks in existence capable of accommodating vessels like the *Lusitania* and *Mauretania*, and it is well known that before these two great ships could enter New York harbour extensive dredging had to be undertaken in order to deepen the channel. Finally, the size of the ships of the future will be determined, as heretofore, by the demands of trade; and if the shipowner can find cargoes in large enough quantities, or passengers sufficiently numerous, to employ profitably larger vessels than are now afloat or under construction, he will have no difficulty in finding a shipbuilder able and willing to meet his requirements. Judging from past developments, it is not unreasonable to prophesy that the next few years will see the launch of transatlantic leviathans 1,000 feet long, and with a displacement proportionately increased.



A COMPARISON THAT SPEAKS FOR ITSELF.

BUILDING THE FORTH BRIDGE.

GENERAL VIEW OF THE FORTH BRIDGE, LOOKING NORTH. (*Photo, J. Valentine and Sons.*)

THE STORY OF THE FORTH BRIDGE.

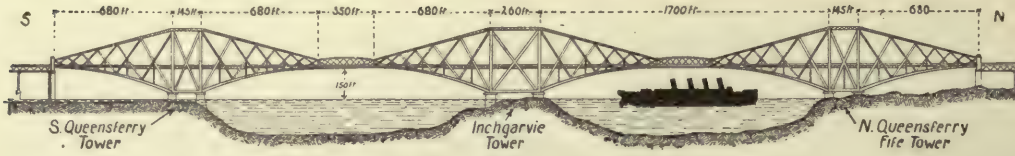
WE have read on a previous page how the existence of the broad Severn estuary forced a railway company to spend some hundreds of thousands of pounds on driving the longest of submarine tunnels. In this chapter we shall give our attention to the great bridge which has done for the counties bordering the Firth of Forth what the Severn Tunnel did for South Wales and the mid-western counties of England.

The Firth of Forth.

If a line be drawn from North Berwick, in Haddingtonshire, to Anstruther, in Fife, and that line be considered to separate the open sea from the estuary of the Forth, the estuary may be said to be some fifty miles long. From very early times the folk dwelling north of the Forth felt the great inconvenience of being compelled to ferry across the often rough waters of the estuary, as the only alternative to making a long and circuitous journey *viâ* Stirling to reach the Scottish capital. As a rule they preferred the water, and to meet their needs three recognized points of crossing were established—the ferries from Granton to Burntisland, from South Queensferry to North Queensferry, and at Kincardine. In course of time the railway arrived at the Forth, and crossed it, first at Stirling, then a few miles farther eastwards, at Alloa. But railway passengers bound from Edinburgh to, say, Dundee, had still to make a weary circuit, and the four big railway systems most interested in the matter decided that it would be worth their while to go to heavy expense to cross the Forth much nearer the sea than is Alloa.

How People crossed it in former Times.

As long ago as 1805 some bold spirit had proposed to drive a tunnel under the river at the Queensferries. But very naturally, considering the condition of the engineering



ELEVATION OF THE FORTH BRIDGE, SHOWING PRINCIPAL MEASUREMENTS.

Under the north span is seen a vessel of the relative size of the *Lusitania*.

science of the time, this proposition began and ended on paper. Thirteen years later Mr. James Anderson of Edinburgh came along with plans and elevations, all complete, for a bridge at the same site. His designs show three suspension spans of 2,000 feet each—and also, we would venture to suggest, considerable ignorance of the problems which he had set himself to solve, as the whole structure was not to include more than 2,500 tons of iron. If his scheme had reached the construction stage, it would beyond doubt have afforded an excellent, if disastrous, example of "how *not* to do it."

Barren Schemes for Tunnelling—

And Bridging the Forth.

Passing over the abortive scheme of the North British Railway in 1860 to throw an arched bridge over the river five miles west of the Queensferries, we come to that of 1873, which is coupled with the name of Sir Thomas Bouch. This engineer, at the request of the Forth Bridge Company, backed by the Great Northern, North Eastern, Midland, and North British Railway Companies, drew out four alternative specifications for a suspension bridge to be erected between North and South Queensferry. The design authorized by a Parliamentary Act had main towers 550 feet high, and spans of 1,600 feet. Work had been actually begun when the collapse of the Tay Bridge, in December 1879, caused the promoters to reconsider the whole matter, and abandon Bouch's design.

Sir Thomas Bouch's Designs.

The need for a bridge remaining imperative, Messrs. Fowler and Baker, the eminent firm of engineers, were called upon for other designs. They submitted drawings for a cantilever bridge of enormous and quite unprecedented size; and these having been approved by the Bridge Company, Parliamentary powers for erection were sought and obtained in 1882.

The Final Scheme.

As a result of the engineers' ability we now enjoy the use of the mammoth steel structure which efficiently and gracefully, if not beautifully, spans the Forth, and bids fair to span it for many years to come, given freedom from earthquakes and hostile dynamite.

Since the reader may possibly boggle over the term "cantilever," be it stated that a cantilever means a bracket. The ordinary balcony is a cantilever of a kind. Imagine a large plank laid from a balcony at one side of a street to a balcony on the other side, and you have a partial representation of the principle of the Forth Bridge. We say partial, because it was essential that the cantilevers should be built out in pairs from central towers to balance one another as they grew.

Meaning of "Cantilever."

We will now dissect the dimensions of the bridge, so as to get a grasp of the magnitude of the task of building it. The supports are three towers, each 342 feet high, reckoning from the top of the four piers on which each stands. A tower is composed of four enormous vertical tubes, 12 feet

Dimensions of the Bridge.

in diameter, braced together diagonally in all directions, and connected top and bottom by enormously strong horizontal members. Viewed from the side, these tubes appear vertical, but they are really parallel only in the direction of the axis of the bridge, as a uniform "batter" of 1 in 7½ diminishes the base distance of 120 feet between the two pairs of columns, centre to centre, to 33 feet at the top. The north and south towers are each 145 feet long between centres of columns, while the central, or Inchgarvie, tower has a length of 260 feet, for a reason to be explained later.

The Cantilevers.

Turning next to the six 680-foot brackets, or cantilevers, we may note that each has a roughly triangular shape. At the columns it is 330 feet high, but gradually tapers to 34 feet at the end posts. It is made up of tubular bottom compression booms, tapering from 12 feet in diameter at the piers to 3 feet square at the outer extremities; of a massive lattice-work top tension member; and of six tubular struts and as many lattice ties to the side, making six "bays." These various parts are, like the towers, stiffened laterally by a number of diagonal and cross ties; and, as the sides of a cantilever have the same batter as the towers, they are much narrower at the top than at the bottom. In short, from whatever point they be viewed—sideways, endways, or vertically—the influence of the triangle is obvious.

Suspended Girders.

In addition to the six cantilevers there are the two components, which may be considered the counterparts of the plank connecting our two balconies. These, known as "suspended girders," are 350 feet long each, and rest on the two pairs of cantilevers which they join. Though small as compared with the rest of the bridge, they would, if placed elsewhere, attract considerable attention, and their individual weight of 820 tons certainly commands respect.

The Approaches.

The two main spans have each a length of 1,710 feet, and at present are the longest bridge spans in the world. Adding to them the two end cantilevers and the three towers, the length of the main steelwork comes out at 5,330 feet. The bridge proper also includes a north and a south approach, 1,989 and 968 feet long respectively, made up of arches and girders based on tall masonry piers, which carry the track into the cantilevers at an elevation of 150 feet above high tide. The grand total is therefore about 8,300 feet between abutments.

Why the Present Site was chosen.

As in the case of the Britannia Tubular Bridge, described in a previous chapter, the engineers were aided by a rock situated in the middle of the channel, or, to be more correct, separating the deeper waters of the Forth into two channels of almost equal width. Inchgarvie is its name. Another reason for selecting the site chosen was the triangular tongue of land projecting southwards from the Fife shore, and here reducing the Firth to about one-half of its average width, as reckoned over several miles. It was also fortunate that the general level of the land on both shores was such as to suit a rail level on the bridge sufficient to give ample headway for all shipping.

The Three Towers.

The northernmost, or Fife, tower rises on the edge of the north channel; the central, or Inchgarvie, tower stands on the western end of the island of that name, referred to above; while the south, or Queensferry, tower is situated at the southern edge of the deep water of the south channel. The eight piers for the Fife and Inchgarvie towers had a rock foundation; whereas the Queensferry piers had to be based on a hard boulder clay underlying a stratum of gravel,

THE SOUTH APPROACH SPANS, LOOKING NORTH. (*By kind permission of Messrs. Baker and Hurtzig.*)
In the middle distance is seen one of the South Queensferry Caissons afloat.

silt, and sand. The last, therefore, were of the greatest depth, one of them extending downwards 89 feet below high-water level.

Work commenced.

Work on the bridge was commenced at the end of 1882. The first things to be done were to fix the exact positions of the piers for the towers, and to prepare workshops, wharves, jetties, etc., for handling the immense quantities of metal and stone required for the enterprise. The centre points of the piers were established by a series of triangulations based on lines of known length fixed on the shores, and verified by means of a steel wire carefully measured in the following manner. Two posts carrying knife edges exactly 1,700 feet apart were set up beside the North British Railway. The wire was then passed over the knife edges, and tightened till it had a certain amount of droop at the centre. The droop having been measured by level, and the temperature noted, the wire was marked by copper tags soldered to it at the points where it had rested on the knife edges. By straining the wire subsequently over posts which had been set up on the Fife shore, on Inchgarvie, and at the edge of the south channel, in accordance with the trigonometrical observations, and by giving the wire the original droop at the original temperature, the calculations were checked and found to be accurate within an inch or two.

Measuring Operations.

On the Queensferry shore the sloping ground was terraced over an area of sixty acres to accommodate the workmen and their families, drill-roads, storehouses, timber

yards, and workshops of all descriptions. Here, too, rose a large drawing-loft with a blackened floor 200 by 60 feet, on which all parts of the steel-work could be designed full size. The workmen also busied themselves with the construction of a jetty 2,100 feet long running out from the South Queensferry shore through shallow water to the site of the Queensferry piers. Simultaneously, jetties were built at Inchgarvie, and the whole area enclosed by the central piers was covered by a substantial platform of timber and iron girders, while the actual sites of the piers were being levelled and otherwise prepared. On shore masonry gangs pushed forward the piers for the approaches; so that from the beginning of 1883 the work was being prosecuted at many points at the same time.

Work on Shore.

The Queensferry Jetty.

The twelve circular piers carrying the main towers have—with the exception of the north-east and north-west Fife piers—a top diameter of 49 feet. They increase their diameter downwards to 55 feet at low-water level, below which point, in the case of the Queensferry and Inchgarvie piers, material changes from granite to mass concrete, extending to the natural foundation on which the pier rests.

The Circular Piers.

As the Fife piers were built on practically dry ground, we need not concern ourselves with them, reserving our space for a brief description of the building of the other eight. This necessitated the use of circular steel caissons, to exclude the water from the foundations, of which they formed the permanent exterior. The caissons employed for the Inchgarvie north piers were open at the top; while the other six were provided with an air-tight deck seven feet above the bottom, and thereby converted into huge diving-bells in which the men could attack the ground dryshod. The caissons were made up of two parts—the cylindrical, and the taper. The first, which varies in height, has an external diameter of 70 feet. The tapering part is 24 feet high in all cases, and decreases to 60 feet in diameter at the top, situated at low-water level.

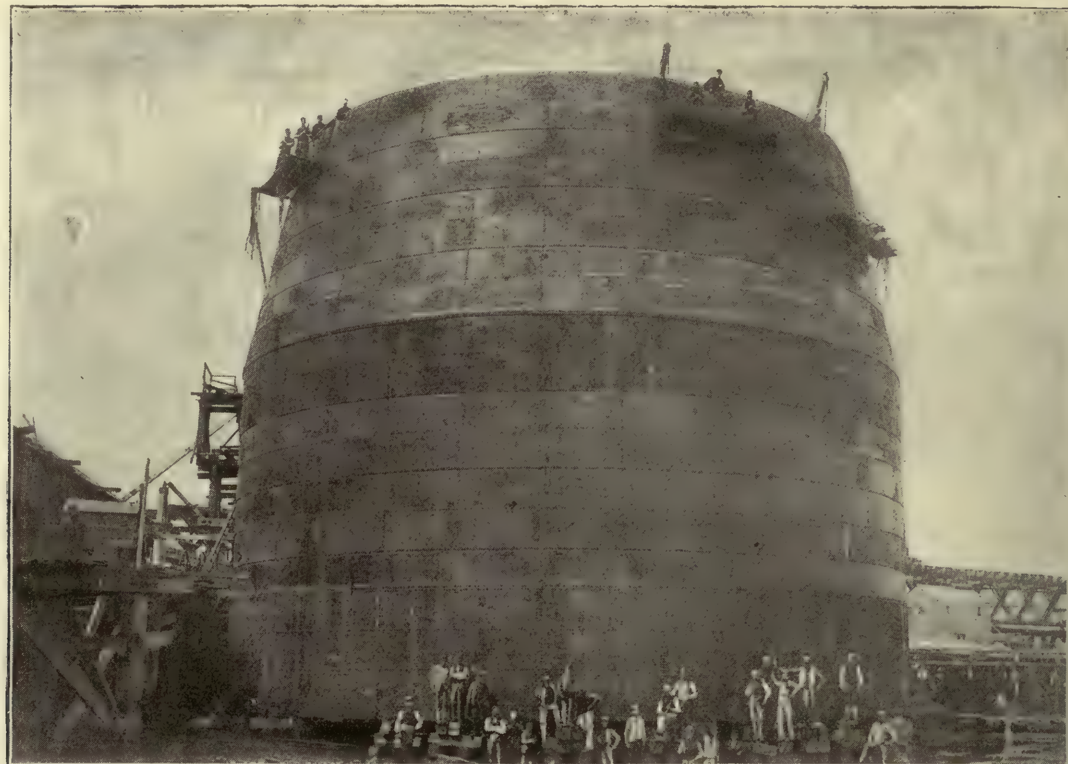
Use of Open and Hydraulic Caissons.

The foundations for the Inchgarvie north piers were surveyed by means of a floating circular stage, from which soundings were taken every six inches round the circumference. In accordance with the readings obtained the bottom of the caisson was shaped, so as to fit fairly accurately into an annular groove cut into the rock. All existing gaps and cracks were then staunched with cement and clay, after which the water was pumped out and the caisson used as a half-tide dam—that is, work could proceed inside till the tide had reached half its full height, when, to preserve the stability of the caisson, valves were opened to allow water to flow in. At a corresponding point in the ebb the valves were closed, and the interior emptied again.

Soundings for the Inch-garvie Foundations.

The Inchgarvie south piers being in deeper water, the procedure was different. After the preliminary survey with the floating stage, to ascertain the contour of the rock, a level foundation was built up with sandbags, to give the caissons an even bearing all round. When floated across from the Queensferry shore, on which they had been constructed, the caissons were moored in their exact positions, and gradually loaded with concrete till they grounded at low water. As soon as the cutting edge had obtained a satisfactory bearing, blasting of the rock commenced. Holes were bored with hand and pneumatic

Sinking an Inchgarvie South Caisson.



INCHGARVIE SOUTH-WEST CAISSON ON LAUNCHING WAYS. *(Photo, J. Valentine and Sons.)*

These huge steel structures, which formed the skin of the below-water foundations of the tower piers, were 70 feet in diameter.

drills, and charged with dynamite cartridges connected to an electric battery. When the men had withdrawn, the pressing of a button fired all the charges simultaneously. A copious supply of high-pressure air was then blown through the chamber to expel the foul gases, and the gang descended to clear away the *débris*, which was loaded into skips and sent up through special shafts and air-locks to the upper deck. It was necessary to undercut the edge of the caisson very carefully, and by means of the depth of the cut to counteract any tilt from the perpendicular. The sandbags, which had been piled as a support, were displaced gradually, and pushed down the rock until the cutting edge had worked right through them. Every now and then fish, attracted by the glare of the electric lamps inside the air-chamber, would come to the gaps between the bags and peer in, wondering, no doubt, what strange beings had invaded their haunts.

Use of Compressed Air.

The Inchgarvie caissons were all in their final positions by the beginning of October 1884, and the piers on them completed by February 22, 1885.

The Queensferry Caissons.

The Queensferry caissons are the deepest of the eight used. They reached depths of 71, 73, 85, and 89 feet respectively below high-water level. Owing to their very exposed position in open water, they were provided with temporary caissons about 20 feet high added to the top of the tapering portion, to exclude the waves while the masonry was built up. All had a double skin, the inner one splayed out at the bottom to meet the other at an acute angle and form a cutting edge. As

they bit into the ground easily, it was of the utmost importance to centre them correctly before sinking, and this proved a matter of no small difficulty, owing to the strong currents, violent waves, and high winds that vex the Forth. Foreign workmen—Italians, Frenchmen, Belgians, Austrians, and Germans—were engaged to excavate the foundation, being experienced hands brought over by M. Coiseau, the sub-contractor for the work, and able to stand the highly-compressed air needed at the greatest depths.

The Caissons floated into Position.

Each of these four caissons had three shafts, 3 feet 7 inches in diameter, connecting the air-chamber with the platforms above—two for the removal of *débris*, one for the ingress and egress of the men. Fitted with its temporary caisson, stagings, machinery, and a ballasting of concrete, a caisson had a launching weight of over 3,000 tons; yet so great was its bulk that it floated high in the water while being towed to its position in one of the four openings left for it at the north end of the Queensferry temporary jetty. On reaching its destination it was moored into place and weighted very carefully, so as not to press too heavily at low tide on the mud and silt. For the removal of the last the engineers employed an ejector of a simple kind—a pipe leading from the air-chamber, where it had a flexible end, through the sides of the caisson above water level. The method of using the ejector may be thus briefly described. Water was forced into the chamber and mixed with the mud to reduce it to a semi-fluid condition. One man then opened the cock of the ejector pipe, while another manipulated the hose end, dipping it periodically into the "sump" of mud. The velocity of the air gave it sufficient momentum to catch up and carry out some of the liquid. The operator learned by practice how long and how deep to submerge the nozzle to get the best results.

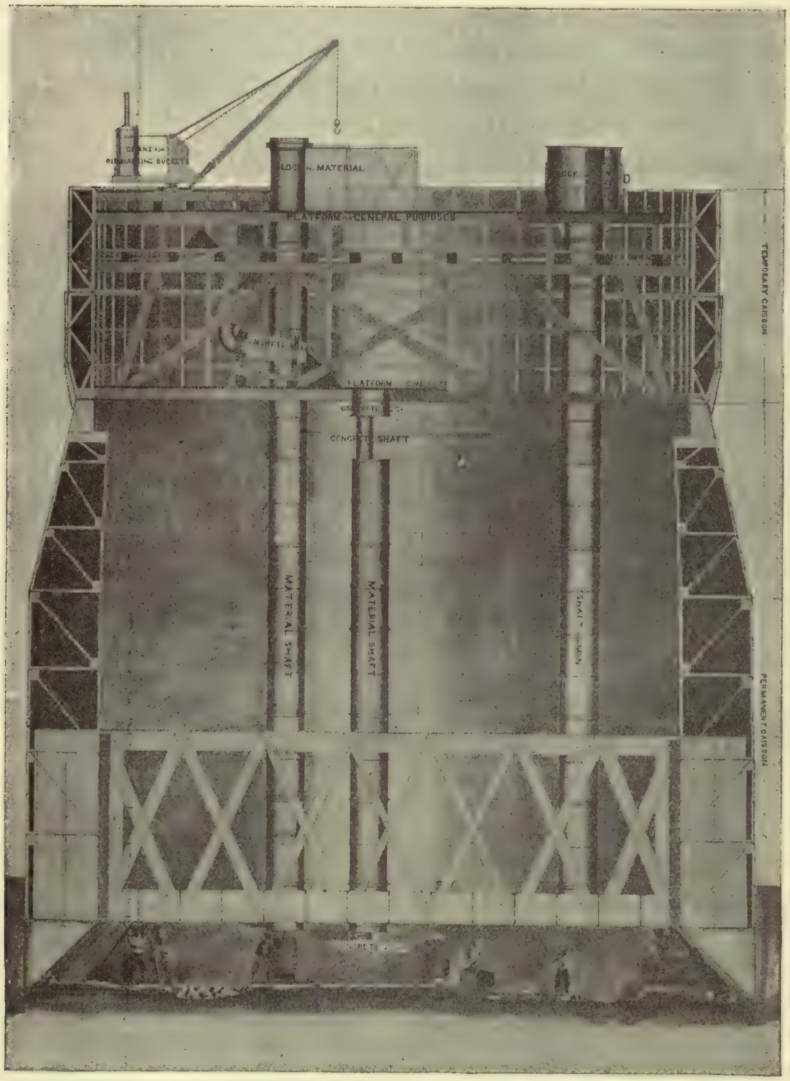
A Mud Ejector.

A Hydraulic Spade for Cutting Clay.

Under the soft upper stratum lay hard boulder clay, of such a consistency as to render ordinary spade work very laborious and ineffective. Owing to its somewhat elastic nature it could not be blasted satisfactorily with dynamite. Excavation had come almost to a standstill, when Mr. (now Sir) William Arrol, the contractor for the bridge, devised a hydraulic digger, consisting of a ram working in a long cylinder and ending in a large spade. On the top of the cylinder was a headpiece to rest against any projection on the roof of the air-chamber which would hold it fast while the water forced the spade to its full depth down into the clay. By means of this device a series of trenches 18 inches deep were dug all over the area covered by the caisson, the edge of which was also undercut with the help of the same instrument.

An Accident to a Caisson.

An accident overtook the north-west caisson while it was being sunk into position. An unusually low tide caused one side of it to settle immovably in the mud, and tilt to such a degree that it was filled by the next tide and driven yet deeper into its bed. Additional rings of plates were added with all possible speed to the top of the ironwork. Unfortunately, the men in charge of the pumps emptied the caisson more quickly than the carpenters could place the internal stiffening struts, with the result that the plates gave way under the pressure of the water outside for a distance of 30 feet. Here was a disaster indeed, though not sufficient to dishearten the workers. After mature consideration it was decided to surround the caisson with a timber barrel reaching some distance above high-water level. At the top this was supported by a heavy circular timber frame, at the bottom by the iron plates of



SECTIONAL VIEW OF CAISSON. *(Photo, J. Valentine and Sons.)*
Showing working chamber at the bottom, with men using hydraulic spades, shafts for men and materials, air-locks, platforms, etc.

the caisson. The operation took nearly ten months, but it proved a great success. The caisson floated once more, and reached its final position nearly a year after its three fellows—namely, in February 1886.

Filling up the Air-chambers.

When excavation under the caisson had been completed, the air-chamber was cleared of all materials used during the sinking. The smiths then provided the bottom of the material shafts with flap doors opening downwards, and replaced the large locks at the top by smaller ones. At a given signal the men below closed the flap of a shaft. Those above opened the cock and filled the tube up with freshly mixed concrete. Then the cock was closed and the first party admitted air into the shaft above the concrete, and, when the pressure there was the same as that in the chamber, released the flap, allowing the contents of the shaft to pour out. The concrete was then rammed hard into every hole and cranny, from floor to roof, work proceeding from the circumference towards the shafts, which, after the men had finally withdrawn, were filled with cement grout.

The Granite Piers.

The next operation was to fill the caisson space above the air-chamber with concrete up to low-water level. When the material had set, granite courses were built on it to a height of 18 feet above high-water level. Three stout iron rings, incorporated into the work, reinforced the granite, in which were enclosed forty-eight steel bolts, 25 feet long and 2½ inches in diameter, having a 2-foot square anchor-plate at the bottom, and a long screw thread cut on the top, where the diameter increased to three inches. The greatest care was needed to keep this large array of bolts in the exact positions corresponding to the holes in the massive bed-plates which crowned the pier.

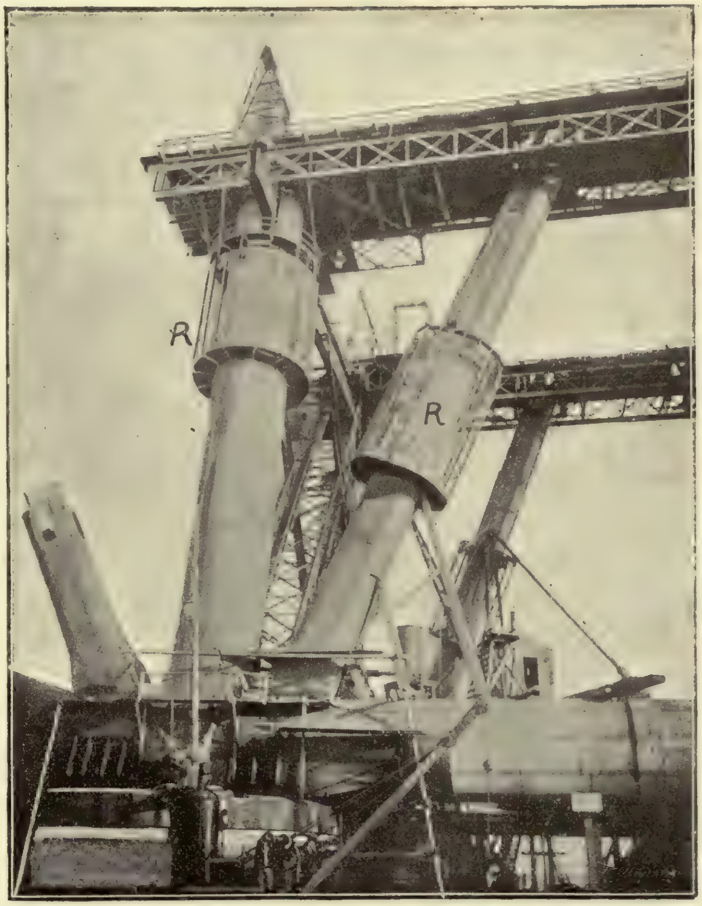
A bed-plate was 37 feet long and 17 feet

wide, weighed 44 or 33 tons, as the case might be, and included five layers of plates, one inch thick each on the average. The topmost layer was practically only a rim round the outside. All rivets were countersunk and chipped flush with the plates so as to give perfectly smooth surfaces. A couple of layers of canvas saturated with red lead served to prevent any water finding its way in between the carefully levelled top of the pier and the bottom of the bed-plate. The accuracy of the bolt-work was such that, though plate holes and bolts made an almost tight fit, the plates passed down the bolts without any forcing.

The Lower Bed-plates.

Before going further, a few figures concerning the first section of our subject — the foundations and piers — may be given. The caissons contained 400 tons of steel and 2,300 tons of iron. More than 33,000 cubic yards of excavation were needed for the foundations, which consumed 44,000 cubic yards of concrete, 2,538 yards of brickwork, and 2,625 yards of rubble. Into the piers were built 29,510 cubic yards of rubble, and 135,386 cubic feet of granite, besides 300 odd tons of iron belting and bolts, anchor-plates, etc. These quantities will give some idea of the scale of operations. As the piers and their foundations are for the most part out of sight, it is interesting to notice that the Inchgarvie north-west pier (including caisson) would, if stood on an open field, tower 107 feet into the air, and have a greatest diameter considerably exceeding the length of a cricket pitch.

Facts and Figures.



THE FIFE TOWER IN COURSE OF CONSTRUCTION.

R R, Riveting Cages.

THE SUPERSTRUCTURE.

We now come to the steel superstructure based on the twelve main piers. Beginning at the bottom, we encounter first the *upper bed-plates*, which form the lowest part of the giant *skew-backs*, from which spring a large number of the main members of the bridge.

"Skew-backs."

A matter which exercised the engineers considerably was the need for providing against the effects of wind pressure and changes of temperature upon so huge a structure of steel. To grasp the problem fully, one must bear in mind the fact that the horizontal members of the towers were as

liable to expand and contract as were the members of the cantilevers and suspended girders. For this reason it was impossible to anchor all the tower columns immovably to their piers. Had such a thing been done, great cold would have tended to draw the piers together and the intense heat of summer

Provisions for Expansion of the Metal.

pier heads. To the bottom of each upper plate was attached a key-plate, circular at the "fixed" points, and oblong at the others, engaging with recesses of corresponding shape in the lower bed-plates. The appended diagram on page 331 will explain better than words the shapes and functions of the key-plates. The letters C C C indicate the fixed points, A A A A the key-plates able to move

TOWERS COMPLETE, BOTTOM BOOMS AND FIRST STRUTS PARTLY BUILT.

(By permission of Messrs. Baker and Hurtzig.)

to thrust them further apart, to the utter destruction of the masonry or steelwork.

It was therefore decided that each tower should be fixed at one corner only, and that a certain amount of movement should be possible at the other three. For the sake of exactness we should add that even at the "fixed" corner a slight circular movement was allowed. The system adopted included upper bed-plates anchored to, but able to slide upon, the lower bed-plates affixed to the

Key-plates.

in *all* directions, and L L L L the keys allowed a longitudinal movement and also slight play in a circular direction. The independent but closely fitting packing-plates B B B B prevent L L L L from moving laterally.

Further provision for expansion was made at the end piers of the approaches, and at the Inchgarvie ends of the suspended girders, and for circular movement at all cantilever ends. This subject will be touched again on a subsequent page.

While the masonry progressed the work-

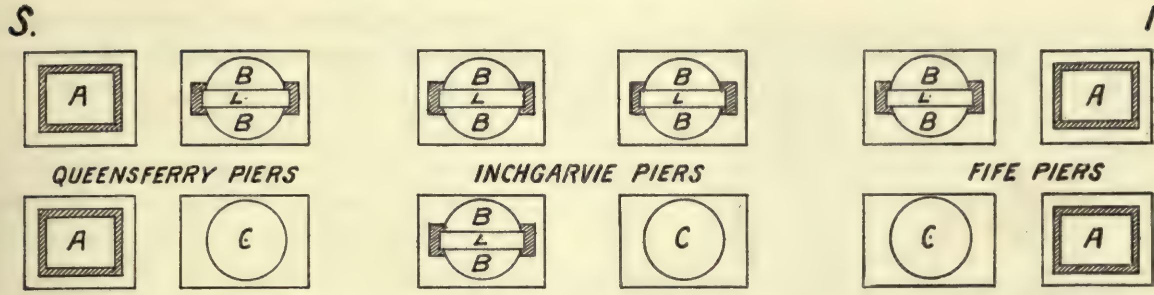


DIAGRAM SHOWING RECTANGULAR LOWER BED-PLATES ON PIERS, AND KEY-PLATES (A A A A, L L L L, C C C) PROJECTING FROM UPPER BED-PLATES.

The shaded areas indicate (on a greatly exaggerated scale) the spaces left between the Key-plates and the depressions in the lower Bed-plates, to allow for movements of the Towers and Cantilevers.

Preparing the Giant Tubes.

shops at Queensferry were fully occupied in rolling, planing, and shaping the plates, beams, and ties of the various bridge members. For the enormous 12-foot diameter columns and bottom members between skewbacks, plates 16 feet long and about 4½ feet wide were bent to the correct curve by special rolls, temporarily assembled, and drilled with all their rivet holes. These gigantic tubes are made up of ten "strakes" (corresponding to the staves of a cask) of plates laid inside and outside alternately round the circumference, and "breaking joint" every eight feet—all plates made flat or butt-end joints with their two neighbours in the same "strake," these butts being covered inside and out by short plates. Internally the tubes are strengthened by longitudinal beams riveted to the plates, and supported inside by circular beams and diaphragms eight feet apart. The 8-foot diagonal tower struts are flattened on both sides, for convenience in making the joints where they cross one another.

Erection of the Steelwork begun.

From each skewback, based on an upper bed-plate, spring five tubular and four lattice girders, which make it a somewhat complicated part of the steelwork. As soon as the skewbacks were finished, the horizontal members joining each skewback to its three neighbours were built on a platform resting on the piers. Then came the erection of the columns and their struts, and the building out of the lower booms and struts of the first bay. At this period each skewback somewhat resembled a huge expanded hand, each finger the commencement of a huge tube, the thumb one-half of a horizontal member between piers.

Movable Platforms for the Towers.

Up to a height of 60 feet above the main staging the parts of the various vertical members were placed with the aid of derrick cranes. When that point had been reached preparations were made for the construction of platforms which should be raised gradually up the columns as the work proceeded. There were two platforms to each tower, running north and south—for 190 feet in the case of the Fife and Queensferry, and 350 feet in that of the Inchgarvie. The platforms rested on four longitudinal girders, themselves supported by two cross beams passing through openings in the top plates of the rising columns. These beams rested on shorter beams inside the columns, under which were hydraulic presses attached to lower inside beams. The two last mentioned sets of beams were supported by removable pins.

A "lift" of the platform was 16 feet,

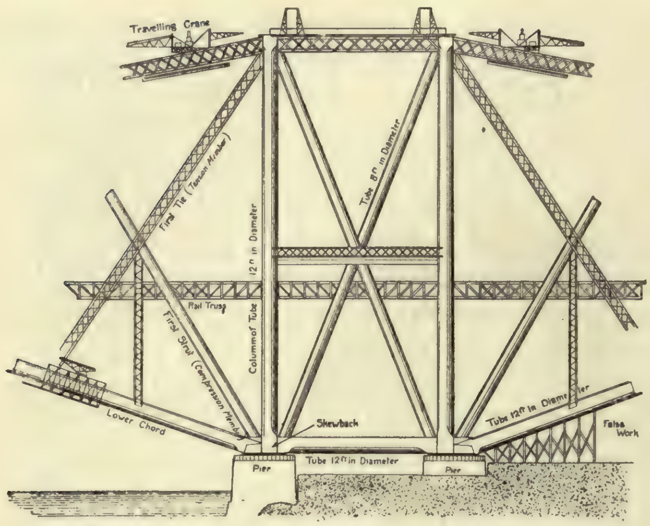


DIAGRAM TO SHOW HOW THE CANTILEVER ARMS WERE BUILT OUT.

performed in as many strokes with the rams, the ends of the platform being raised alter-

Lifting a Platform.

nately. After each stroke the beams immediately supporting the cross girders were pinned in position, and the press girders released and raised by admitting water above the pistons. Then they were pinned in turn and the others released. This operation had to be repeated sixteen times during a lift.

Encircling the columns, below the platform, to which they were attached, were the cylindrical riveting cages, covered in with wire netting to prevent the fall of men, tools, or rivets, etc. At each cage one gang worked outside the tube, another inside. Similar cages were used on the tower struts and the lower booms of the cantilevers.

As the columns were free at the top during

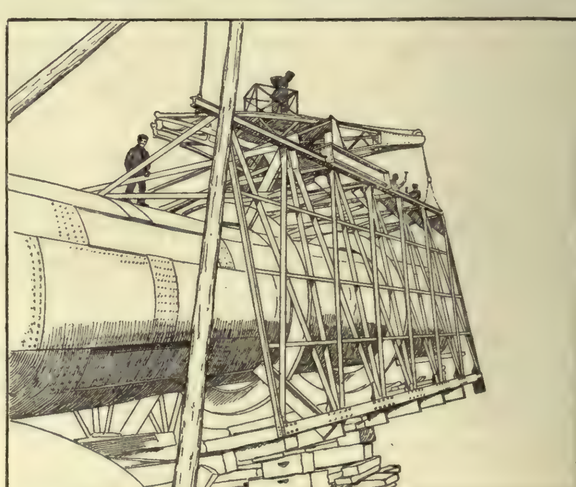
Correcting the Inclination of the Columns.

construction, their own inclination from the vertical, the weight of the platforms, and the wind pressure caused serious deflections, which had to be corrected from time to time by means of wire ropes for pulling inwards and timber struts and hydraulic presses for thrusting apart. Such correction was a delicate operation requiring the greatest care, and, as the columns were terribly stiff, the use of enormous power.

Half-way up a halt was made to build in the crossings of the diagonal struts in the centre of the tower. A

The Final Elevation reached.

crossing contains, in the case of Inchgarvie, 80 tons of steel on each side of the tower. When they and the horizontal bracings were finished, the platforms resumed their upward journey to the top—reached at a height of 360 feet above high water, practically identical with that of St. Paul's Cathedral. They there almost touched one another, having drawn closer and closer as they rose. The gap was covered over so as to form one large platform of more than double width, and, the longitudinal girders were stiffened with heavy chains to prepare for the construction of the lattice-work horizontal ties connecting the column summits. These ties were soon put together and joined to the top skewbacks, from which, as from their larger brethren beneath, members run in many



BUILDING OUT A LOWER BOOM. RIVETING CAGE STARTING ON ITS JOURNEY.

THE QUEENSFERRY NORTH CANTILEVER AS IT APPEARED FROM THE QUEENSFERRY PIERS, APRIL 15, 1889.

This view gives some idea of the complexity of the steelwork.

(*By permission of Messrs. Baker and Hurtzig.*)

directions. Cross girders and diagonal ties added, the highest part of the work was complete, and a solid foundation ready for the fixed platform required as a base of operations for the building of the top members of the cantilevers and of the struts and

ties below. Regular workshops were erected at this great elevation, to which derricks lifted the parts of two large jib cranes destined to construct and travel down the top members on a frame from which hung a platform for the workmen. Each Jubilee Crane, as it was named in

Workshops in the Sky.

the construction of the successive struts, ties, and other members of the six bays in each cantilever. Let it suffice it to say that, so far as possible, temporary supports from above and below were employed to ease the strain of the growing girders and their loads. Periodically the positions of the various parts were checked with reference to the centre

FIFE CANTILEVERS ALMOST COMPLETED. *(By permission of Messrs. Baker and Hurtzig.)*

Observe the travelling "Jubilee" Crane at end of nearer cantilever.

honour of the year, weighed, with its platforms and gear, about sixty-four tons. Yet the top members were called upon to bear this weight entirely by virtue of their own stiffness till they should have grown one hundred feet outwards from the column and met the first supports—temporary ones—built up from the bottom booms. The strain on the steelwork was tremendous, and the risk of serious damage by high winds such as to cause the engineers great anxiety until the junction had been effected.

The Jubilee Cranes.

It would be tedious to describe in detail

line, and corrections made promptly where needed. So well was this part of the work done that the lateral error in an arm nearly 700 feet long did not exceed a couple of inches.

Slowly but surely the Jubilee Cranes and their fellows on the railway viaduct and the bottom booms worked their way outwards, till the end posts had been set. By that time 16,678 tons of steel had been built into the columns, and 32,382 tons into the cantilevers. There remained the task of bridging the 350-foot gaps separating

The Cantilevers completed.

the Inchgarvie cantilevers from their partners of Fife and Queensferry.

Four of the cantilevers terminate in vertical *end posts*. The fixed cantilevers, resting on the ends of the approach viaducts, have, instead of posts, large boxes, eight feet long in the direction of the bridge, through which arch-shaped openings were cut to allow trains to pass. Each box was filled with iron scrap set in asphalt, to give 1,000 tons of dead weight in addition to that of the steelwork of the cantilever, and so to counteract any tendency of the Fife or Queensferry towers to tilt, should two trains meet at the extreme end of the free cantilever on the Inchgarvie side. As an additional precaution the fixed ends—fixed in one respect only, as they could move longitudinally on rollers—were held down by steelwork projecting from the masonry of the last piers of the approaches, in such a way as not to interfere with longitudinal expansion and contraction. Since such a check could not be applied to the Inchgarvie cantilevers, their tower was given a length much greater than that of the other two towers.

Details about their Extremities.

Turning to a consideration of the four "free" cantilevers, we find that their end posts all take the form of a hollow box standing on end, 40 feet high, 3 feet wide, 4½ feet deep, and lacking the top end and the lid, as it were, so that the end posts of the central girders might enter. At the Fife and Queensferry ends the central girders rested on bearings at the bottom of their respective cantilever boxes, which permitted a slight lateral but no longitudinal movement. At the Inchgarvie ends the top members of the girders terminated in a projection, to the under-side of which was attached a huge steel cup, concave side downwards. On the bottom of the corresponding cantilever box was a similar cup; and between the two cups stood a massive steel rocking-post, weighing nearly nine tons, with hemispherical ends to fit the cups. This arrangement caused the bottom of the Inchgarvie cantilever end posts to support the top members of the central girders in a manner that allowed of longitudinal and circular movement within well-defined limits.

A Clever Device.

The cranes that had travelled down the top members of the cantilevers were dismantled when they reached the ends, and replaced by lighter machines suited for the task of building out the central girders from both ends as temporary continuations of the cantilevers. Each girder has eight "bays," a straight bottom boom, and a curved top boom. The end posts of the girder were temporarily attached to the top member of its cantilever by strong plate-ties, riveted and bolted on; while the bottom of the girder and cantilever posts were separated by steel wedges, which could be pushed further in or withdrawn by hydraulic presses. The actual erection of the parts of a girder was a comparatively simple matter; though to make the junction near the centre proved a somewhat difficult business, owing to the constant changes of temperature.

Building the Central Girders.

The bottom booms were joined first, at a time when the thermometer gave a reading of 55 degrees Fahrenheit, the gaps being filled in with cover-plates carefully prepared beforehand. There remained the V-shaped openings in the upper booms, which widened or decreased as the temperature rose or fell, owing to alterations of the curvature of the bottom boom. It was necessary to close the top booms at as *low* a temperature as possible, to put them in a state of compression at average temperatures, just as the bottom boom would be in one of tension—that is,

Joining-up.

when the ties should have been cut and the girder allowed to ride free. It was also essential that the plate-ties should be released immediately, to permit the cantilevers to contract when the air cooled.

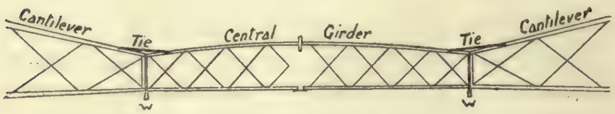


DIAGRAM SHOWING THE JOINING-UP OF A CENTRAL GIRDER BETWEEN CANTILEVERS.

w w, Wedges.

The Fife girder was taken in hand first. Wedge-pieces to fit the top gaps accurately at a certain temperature were made and drilled ready for bolting. Also, furnaces were built round the plate-ties to heat them to redness—and softness—while the riveting-up should be in progress. After several days of waiting the rivet holes in the two ends of the top boom coincided. The wedge-pieces were driven down and made fast, and the furnaces started round the plate-ties. At the critical moment the bolts were knocked out, allowing the girder to ride free on its own bearings as an independent whole.

A Delicate Task.

In the case of the Queensferry girder the heating of the ties was not done fast enough, with the result that the sudden change of temperature sheared the last few bolts, and freed the girder with a sudden shock, which was felt from one end of the bridge to the other, and caused a momentary panic. Thus the completion of the bridge-work proper proved somewhat dramatic.

A Dramatic Episode.

The rails of the permanent way are carried in troughs partly filled with transverse blocks of teak and pine set in asphalt, and with longitudinal teak sleepers held in position by wooden wedges. The rails themselves are of the "bridge" type, with broad bottom flanges and a longitudinal hollow space underneath, into which enters a tongue on the top side of the fish-plates at rail-junctions. Perhaps the most interesting feature of the rail work is the type of expansion joint used at the end of the cantilevers, where a maximum longitudinal movement of two feet is allowed for. At these points the continuity of the rails has to be broken, without depriving the wheels of support. The difficulty was surmounted in the following manner. From one side of the gap a long rail tongue, cut to a point at an angle of 1 in 63, crosses to the trough on the other side, in which it rests on a long flat plate. This plate is attached to the end of the other rail, which is bent outwards from the centre line on the same angle of 1 in 63, and overlaps the tongue for a considerable distance. The inside edge of the flange of the rail tongue has long steps cut in it, parallel to the overlapping rail and pressing against studs in the plate attached to that rail. When the gap between cantilever and girder increases or decreases, the inside edge of the tongue moves parallel to the centre line of the bridge, while the flange pulls the lap rail nearer or allows it to be pushed outwards by the tongue, according to circumstances. In this way the exact gauge is maintained under all conditions.

Ingenious Rail Joint.

The bridge was opened by the (then) Prince of Wales on March 4, 1890—a memorable occasion in the history of engineering.

The total cost of the bridge and its approaches exceeded three million pounds sterling. The foundations and piers, with their 140,000 cubic yards of concrete and masonry, were responsible for £800,000 of this sum. The number of rivets used to hold the 50,000 odd tons of steel together is estimated at six millions. But even these figures are perhaps not so striking as the

L. S. D.

extent of the area to be painted—namely, 145 acres.

A Splendid Success.

Though, owing to circumstances which prevented the employment of supports in the channels, erection was extremely costly, the result of those eight years of strenuous work cannot be thought anything else than a magnificent success, a splendid triumph for designers, contractors, and workmen alike. Were the bridge to be built to-day it is probable that more modern methods would reduce the cost of material and labour considerably. Critics have even been heard to declare that they could erect a bridge of the same size and strength for half the money. But words are easier than deeds; and it must be an ungenerous soul that would fail to give the honour due to the men who spanned the Forth in four mighty strides, and benefited railway communication on the East Coast of England and Scotland to an extent hardly to be calculated in mere pounds, shillings, and pence.

THE FORTH BRIDGE AS IT WOULD APPEAR IF SET DOWN IN LONDON.

THE EL KOYE BRIDGE IN THE YARMUK VALLEY, BETWEEN HAIFA AND DERAA.

This view gives a good idea of the wild ruggedness of the country through which the Hedjaz Railway passes.

The Hedjaz Railway

THE RAILWAY OF THE PILGRIMS

MONUMENT AT HAIFA STATION, THE SEA TERMINUS OF THE RAILWAY. ERECTED TO COMMEMORATE THE CONSTRUCTION.

THE vast majority of railways are intended for transporting passengers and merchandise from point to point to serve the ends of ordinary social and commercial life. A very small number have been built with the object of concentrating troops upon a frontier—strategic railways. One railway, and one only, owes its existence to religious motives, and that one is the Hedjaz line, which, as will be seen from our map, starts at Damascus—the Gate of Allah—and runs almost due south for more than 820 miles to Medina, the burial-place of Mohammed.

Its Religious Origin.

Except for a comparatively short distance at its northern end, this remarkable line traverses country so wild and sterile as to render any prospects of dividends extremely doubtful. This fact does not affect its importance, however, as the metals were laid with the express—we might almost say sole—purpose of carrying Moslem pilgrims to the holy cities of Hedjaz—Medina and Mecca—to which every Mohammedan is in duty bound to make the Hadj, or sacred journey, at least once in his lifetime, no matter how remote his country may be.

The Turks of Turkey in Europe and of Asia Minor form a very important section of the followers of the prophet, for is not the temporal head of the Ottoman Empire also the spiritual head of Islam? To reach the holy cities from the Levant a pilgrim might either make for Damascus, and thence trace, in fifty-two stages, the painful overland route through the land of Moab and Arabia Petræa, exposed to the greatest privations, scorched and parched and blistered by the sun, plundered and maimed by fierce brigands; or he might take ship to Jeddah, the Red Sea gate to the shrines of his religion. The sea voyage on a crowded, often plague-stricken ship was hardly less tedious and dangerous than the land journey; and common to both alternatives was the march through the country lying between Mecca and Medina, a rough, cruel country haunted by robber bands.

The Old Methods of reaching Mecca.

MAP SHOWING THE HEDJAZ RAILWAY.
Dotted lines indicate sections under construction or projected.

The Moslem of the more rigidly orthodox type regards these trials as a worthy part of the pilgrimage — on the principle that the greater the suffering the greater is the merit. But to many of his creed, and for various reasons, a less painful access to the tomb and birthplace of Mohammed was devoutly to be desired. Moreover, the fact that Jeddah could be closed to pilgrims by a hostile fleet contained an element of religious and political danger. To reach Jeddah by sea the Moslem must thread the easily blockaded Suez Canal, which also exposed the port to easy attack by European Powers. The existence of this danger on the flank had a bad effect upon Asiatic subjects of the Sultan, who, to combat this disquieting state of affairs, conceived, in the year 1900, the idea of pushing a line from Damascus, already connected by rail with Mediterranean ports, through his own dominions to the holy cities of the Hedjaz, and so nullify a siege of Jeddah. In the future, when the line should have been linked up with the Bagdad Railway *viâ* Aleppo and Tel Habesh, an all-rail journey from the very shores of the Bosphorus would be secured.

Jeddah exposed to Attack.

The time was ripe for the idea. The faithful throughout the world, so far from pouring ridicule on the Sultan's proposal, hailed it with enthusiasm. Nor were they content with words, as they poured in their subscriptions in generous measure to hasten the realization of this notable project. The Government, infected with a like spirit, handed over to the Commission appointed to carry the matter through seventeen million unused postage stamps to be sold by public auction for the good of the cause.

The Sultan's Proposal.

The rapidity with which things now moved was a revelation to those who regarded the Turk as a constitutional sluggard. The word "to-morrow" was forgotten. A wave of energy swept over the nation. The Sultan secured forthwith the services of an extremely able German engineer, Meissner Pasha, as commander-in-chief of a large working force, and selected for his lieutenants Marshal Kiazim Pasha and Haiji Mukhtar Bey; these last controlling in turn engineers of various nationalities in charge of sections—all imbued with the same enthusiastic desire to fulfil with the utmost speed the royal command.

An Enthusiastic Reception.

The initial survey of the first section south from Damascus was put in hand at once. Simultaneously all preliminary arrangements were made with regard to gauge, rails, type of track to be laid down, and building equipment. The greater part of the rails and other material was purchased in Belgium, Russia, and the United States. We may mention in passing that the gauge selected

was that of the line linking Damascus with the sea—one of 1·05 metres, or 41·3 inches.

Beirut was chosen as the landing-point for material for the first stage, which starts at Damascus. At the time when operations commenced, a short line, built by French capitalists, already ran southwards through a profitable agricultural belt, which may presently be very highly developed. The route chosen for the sacred railway lay almost

The Haifa Branch.

SAILORS LANDING CONSTRUCTIONAL MATERIAL AT THE WHARVES, HAIFA.

parallel to and eastwards of the French track, as far as Deraa. This last was the natural point at which to run off a branch line to Haifa on the Mediterranean. Haifa is destined to become an important place as the sea terminus of the railway. A fine harbour is to be constructed to give safe anchorage to vessels of deep draught. On the land the visitor now sees substantial terminal buildings, surrounded by extensive sidings, and dominated by the imposing monument raised to commemorate the building of the railway.

The construction of the Haifa-Deraa section was in itself a notable undertaking. The country, rugged and broken by yawning ravines, involved the surmounting of numerous engineering difficulties. To secure the necessary easy grade the line has to follow a somewhat meandering course, especially in the neighbourhood of the deep gully through which the Jordan finds its way after leaving the Lake of Tiberias. Though the river lies 800 feet below the level of the Mediterranean, the work of carrying the rails up to the high ground on either side has been done so well that no abnormally heavy gradients are encountered.

On this 100-mile stretch, which includes seven long tunnels and a number of deep rock cuttings and large viaducts, a cosmopolitan army of workmen—Italians, Montenegrins, Greeks, Turks, and other Europeans—were kept busily at work.

After crossing the Jordan by a handsome masonry bridge of seven arches, the line bends sharply to the north-east round a bluff, and turns eastwards to effect a junction

A TYPICAL STRETCH OF THE ARABIAN DESERT THROUGH WHICH THE LINE PASSES, 530 MILES SOUTH OF DAMASCUS.

with the French Hauran Railway running south from Damascus. A sharp twist to the south-east brings the metals to a junction with the main line at Deraa. As the map shows, a round route is then established between Deraa and Damascus, over the metals of the French and Hedjaz railways, both of which have a common outlet to the sea.

As soon as this link was completed a train service was inaugurated between Haifa and Damascus; and an already considerable tourist traffic is increasing rapidly, as also the trade in agricultural produce raised in the province traversed by railway.

From Deraa the line ascends gradually an undulating plateau to Zerka, where it drops into a deep valley, and climbs out of the same by a winding ascent on to another small fertile belt. As the line proceeds southwards signs of civilization become fewer and fewer, and the sense of wild desolation more pronounced. Pursuing a course roughly parallel to the Jordan, and almost identical with the old caravan route, the railway traverses a country which is full of history and romance to the religious mind—as much so to the Christian as to the Mohammedan. Decayed ruins of a past civilization and silent monuments of a long-departed prosperity are visible on all sides.

Travelling southwards.

At a point approximately abreast of the Dead Sea the railway enters a barren waste. A foot-traveller passing through this region must be astonished at encountering the steel rails and telegraph poles which mean easy communication with distant but more hospitable districts. The interminable level of

MASONRY BRIDGE AND WATERFALL IN THE TEL-EL-SHIHAB, 90 MILES FROM HAIFA.

sand is broken only on the western horizon, where the mountains of Moab raise their peaks dimly into the heated air.

For a considerable distance the going is easy enough from the engineering point of view. The valleys are wide, and contain no steep grades; the engineer could pick his path and lay his iron road in such a manner as to minimize the work to be exacted from the locomotives.

But in one respect the country is difficult: it is practically waterless. During construction every drop of water used by the army of workmen had to be conveyed by train from the nearest well—in some cases many miles away—and stored in jealously guarded tanks. Here and there wells have been sunk with success, and windmills, urged by the desert breezes, raise the water into cylindrical iron reservoirs perched on masonry piers, which by their shape recall the Martello towers to be seen along the south coast of England. In short, the task of supplying workmen, engines, and the pilgrims who, being too poor to take advantage of the line, still tramp the weary distance on foot, has been, and is, a problem of no mean order.

Lack of Water.

As the railway approaches Ma'an, 285 miles from Damascus, it climbs steadily on to the back of a plateau more than 3,000 feet above sea-level. Ma'an itself is now quite an important place on account of its hospital, hotel, repairing shops, and other buildings, all substantially built in stone, and designed to resist attacks by any of the rebellious tribesmen, who own a very reluctant allegiance to the Sultan, and consider their private interests to be threatened by the advent of the railway. The villagers themselves, once daring smugglers of arms and ammunition, have found a safer and equally lucrative source of revenue in the letting of their houses to railway officials and to the officers of the garrison stationed at the place, which may be regarded as the gateway of Syria, and is therefore important strategically as well as commercially. In time to come it may also find favour as a health resort, since the air, despite frequent dust storms, is very invigorating.

Ma'an.

Southwards of Ma'an the line traverses high ground more desolate, if possible, than the country already crossed—certainly more rugged and wild. Of vegetation, except in a few little valleys, there is none; and here the transport animals of the pilgrims have perished in countless numbers. On all sides are sand, boulders, and deep ravines. About 50 miles from Ma'an, at a point where the rails have attained an elevation of 3,700 feet, the plateau ends abruptly, and there is an almost precipitous drop of 500 feet into the wild ravine called, appropriately enough, Batn-el-Ghrul (or Batn-el-Ghoul), the Devil's Belly. Standing on the edge of the sandstone escarpment, which runs almost 40 miles east to west, the traveller has a magnificent view of the great basin-like inland depression of the south, tinted with all the colours of the spectrum. This depression extends some 120 miles to the gorge at Kelaat-el-Akhdar. Half-way down it rise the flat-topped isolated hills of the Haraat-i-Ahmar; and towards the southern end is visible the great pinnacle of the Jebel Sherora, shaped like a boar's tusk, and towering some 2,000 feet above the plain. On both sides beetling cliffs give a sharp outline to the basin. The scene, thanks to the clear desert atmosphere, is one which lingers long in the memory of the spectator.

The Devil's Belly.

To the engineer the existence of the escarpment was a serious obstacle. The lower level had to be gained somehow. As time and money were alike valuable, a wide detour, which should take the ravine in flank, as it were, could not be considered. There was

nothing for it but to follow the old pilgrims' track along the very face of the cliff. By an extremely clever piece of engineering the line is carried down to the valley in a long looped curve, parallel to the face of the cliffs. So well was the work done that the grade nowhere exceeds 1·8 per cent. The descent of the ravine is undoubtedly one of the most prominent engineering features of the whole railway, and its execution reflects the highest credit on those who were responsible.

Clever Engineering.

The valley gained, the railway twists in and out among rocky promontories, occasionally tunnelling through an obstacle, and at Wadi Rutm definitely enters the open depression, flanked to the east by the red and yellow sandstone bluffs 20 miles away, and on the west by the black, jagged rocks of the Red Sea watershed. In the valley have sprung up several small settlements since the coming of the railway, notably at Kalaat-i-Mudiverre, and at Zat-el-Haj. At the first of these is procurable, for the first time since leaving Ma'an, a supply of water, raised by a wind-pump from the station well; at the second is seen once more some sign of vegetation—a few palm trees. Four hundred and thirty miles from Ma'an the railway reaches Tebuk, a small oasis which had great importance as a halting-place for pilgrims. Its comparatively abundant wells have also made it an important railway depôt—Ma'an on a smaller scale — equipped with engine-house, extensive sidings, and several stone buildings, of which one is a commodious hospital. When the construction parties first reached Tebuk the inhabitants were very few, as the result of a raid which had driven most of the villagers to take refuge at Ma'an and elsewhere. The name (Tebuk = "treachery") commemorates a treacherous attack made in 629 A.D. by Bedouins on a force being led northwards by Mohammed himself to repel a rumoured Byzantine invasion of Arabia.

To Tebuk.

Shortly after leaving Tebuk the line crosses a wide gully, down which rushes occasionally a turbulent torrent; for even in this arid region rain sometimes falls, and then in torrents. The bridge, or rather viaduct, of twelve arches here is remarkable as being the only one on the line built by the Turkish soldiers.

The plain continues for some distance, and then the ranges of hills converge suddenly from either side, and close the basin. Plunging through a short tunnel, the railway emerges into a narrow valley, up which it climbs easily on a gentle gradient, and passes through extremely fine scenery to Medain Salih, near which the highest point on the line—3,750 feet above sea-level—is attained. The section between Tebuk and Medain Salih was entrusted entirely to the military.

El Ula, 609 miles from Damascus, is possibly the most important station on the railway. Here we find a little town of four thousand souls buried in the heart of the desert. It contains five hundred houses, and boasts copious springs, and a thousand acres planted with date palms and cereals. The station, somewhat imposing and extensive, is the last depôt north of Medina, and close to it are repair shops, engine-sheds, and houses for the railway staff.

El Ula.

Beyond El Ula the infidel may not go. Though Medina is still 210 miles away, Moslem prejudice forbids an unbeliever to approach nearer to the holy city. The journey has, indeed, been made by one or two "pagan" Europeans, but not without great personal risk; and many years must elapse before improvements in means of communication will break down the barrier set up by the devotees of this uncompromising religion. Even Meissner Pasha himself fell under the ban, and was obliged to relegate

A Religious Barrier.

the carrying of the rails into Medina to the very able Marshal Kiazim Pasha, who accomplished the task most creditably, aided by a band of Moslem workers.

The Turks have proved themselves very competent railway constructors. They laid the permanent way throughout, leaving only the station buildings, bridges, and culverts to workmen of other nationalities. The Turkish sailors unloaded railway material at Haifa; Turkish soldiers laid the sleepers and rails. Operations were conducted throughout on a highly organized system. Here is a little picture from the pen of one who watched the Turks at work:—

BUILDING PIERS FOR STEEL BRIDGES ON HAIFA-DERAA SECTION.

The Bridge comprises two 100-foot and one central 166-foot spans.

Construction Work.

"The (construction) train carried several truck loads of rails and sleepers, and as it drew up within ten yards of the last rails laid, the working-parties, some two hundred men all told, formed up on each side of the trucks.......hard bitten picturesque fellows, wearing the agal and keffiyeh instead of the regulation fez, smaller as a rule than Egyptian conscripts, but more active and better made. There was very little shouting and no confusion; every man seemed to know what to do without orders. The rails were lifted in pairs from the trucks and set each upon the shoulders of eight men, who moved rapidly off with balanced step to the laying-point, halted, turned inwards, lowered and laid the rails with automatic precision at the orders of the squad commander, and in a moment were scampering back to the trucks to begin over again; while long strings of men hurried along the embankment with sleepers on their backs, pitched them down on the track, and rushed back as if their lives depended on it for more—and all this in a temperature of 106° Fahrenheit."*

A Well-built Railway.

The solidity of everything connected with this railway is one of its outstanding features. Unlike the majority of such pioneer lines running through a sparsely populated country, it has not been built with the prime idea of getting through as quickly as possible at small cost, and reconstructing on a sounder scale afterwards. It was properly built in the first instance, and its permanent way will compare favourably with any to be found in civilized parts of the world, being ballasted with broken rock and sand, which afford a solid foundation for the rails. The bridges are in keeping with the remainder of the work; their piers of solid masonry rest on solid footings capable of withstanding the scour of turbulent rivers and the blows of floating *débris* carried down

* *The Times.*

by floods. Where exceptionally heavy work was found to be necessary, a temporary bridge was built to carry material for the stretch of line ahead, which was laid while the permanent bridge was constructed behind it. Consequently railhead advanced uninterruptedly.

TURKISH SOLDIERS BUILDING MOAZAMMA STATION AT AN OASIS IN THE ARABIAN DESERT.

For the stone arch bridges ample supplies of material were usually found close to the site, or could be brought up easily by train. Stone was used also for the stations, which have no raised platforms, but merely paved areas on both sides of the track.

The engines used on this line are necessarily of a very powerful type, as they have to haul 250-ton trains up long grades and round sharp curves. The most notable locomotives are those of the articulated compound Mallet pattern, such as have been introduced recently upon several European and American systems. The engines have very large boiler capacity, a heating surface of 1,780 square feet, and a grate area of 27 square feet. As the rails are somewhat light, the engine's weight is distributed over six pairs of wheels, grouped into two sets of three pairs each. The wheels of the rear group are coupled together and placed in the main frame, and driven by two high-pressure cylinders. The second and third pairs of the front group are also coupled, and driven by low-pressure cylinders fed from the high pressure. Since the forward six wheels are mounted in a pivoted bogie truck, the engine, despite its wheel base of 28 feet, is able to negotiate with safety curves of 300-foot radius at high speed. The design of the Hedjaz locomotives includes several other features rendered necessary by the peculiar characteristics of the line. Among these is the provision of unusually large tenders, able to carry five tons of coal and 4,000 gallons of water—this last obtainable, as we have noticed already, at very few places on the railway. In fact,

Rolling Stock of the Line.

OFFICIAL OPENING OF THE TEBUK STATION.

Notice the substantial character of the buildings, and the wind-pumping plant.

TEBUK MOSQUE, THE ONLY ONE BUILT FOR THE LINE.
It was constructed by Christian workmen.

the engine had to be the mechanical counterpart of the "ship of the desert" with regard to its water-carrying capacities. As for the fuel, this is stored at several points on the railway, all kept replenished by special coal trains, which take the mineral aboard at Haifa. The total weight of engine and tender in working order is 89 tons.

The carriages are of the American pattern, commodious, comfortable, and well slung on four-wheeled bogies. They are entered at each end by means of a short flight of steps reaching almost to the ground.

Quick and Creditable Work.

The railway was mooted by the Sultan in 1900, and completed—as far as Medina—in 1908. Considering the immense physical difficulties to be overcome, this means the achievement of a remarkable engineering feat. Practically unknown country had to be traversed. All the material, stores, and provisions for the workmen had to be brought over the rails from the seaboard. Construction included the building of some hundreds of viaducts and bridges and the driving of many tunnels. We must remember, too, that the material had all to be ordered from foreign countries—Turkey has no rail factories of her own—and that it was impossible to do what has been done on many long lines—to construct from several points simultaneously. Nor must we overlook the fact that at many points the workers were threatened by hostile tribes, and had to be protected by soldiers, whose organization put an extra tax on the resources of the authorities.

In spite of all difficulties the railway was laid well and cheaply. The total cost for the Damascus and Haifa to Medina portion was only £3,000,000, or about £30,000 per mile. The lowness of the figures is due in no small degree to the fact that for once Turkish greed was subordinated to religious motives, so that

THE NEBATEAN TOMBS NEAR MEDAIN SALIH STATION, 578 MILES FROM DAMASCUS AND 240 MILES FROM MEDINA.

all the money subscribed for the railway was used for that purpose. This renunciation is in itself sufficient to render the Hedjaz scheme a memorable feature of the Ottoman Empire.

A Look Ahead.

It remains to lay 285 miles of track across the desert from Medina to Mecca. The work is being pushed forward with unabated vigour, and soon it will be possible for Moslems to travel to that—in the eyes of the unbeliever—mysterious city with speed and in such comfort as the pilgrim of other days could hardly conceive as existing outside his Paradise. When the Bagdad Railway has progressed another 200 miles, and the Bosphorus has been spanned by a bridge, Mecca will be in direct communication with Constantinople itself, and the influence of the Sultan must necessarily increase among the Arabian tribes who at present refuse him fealty. Looking still further into the future, we see the great land of Arabia, as yet largely unexplored by Europeans, thrown open to the tourist, who will book right through to it from Paris, Berlin, Vienna, and other great continental cities.

VADI PTIL BRIDGE.
The only one built by Turkish soldiers.

DESIGNING A SHIP.

BY ALBERT G. HOOD,

Editor of "The Shipbuilder."

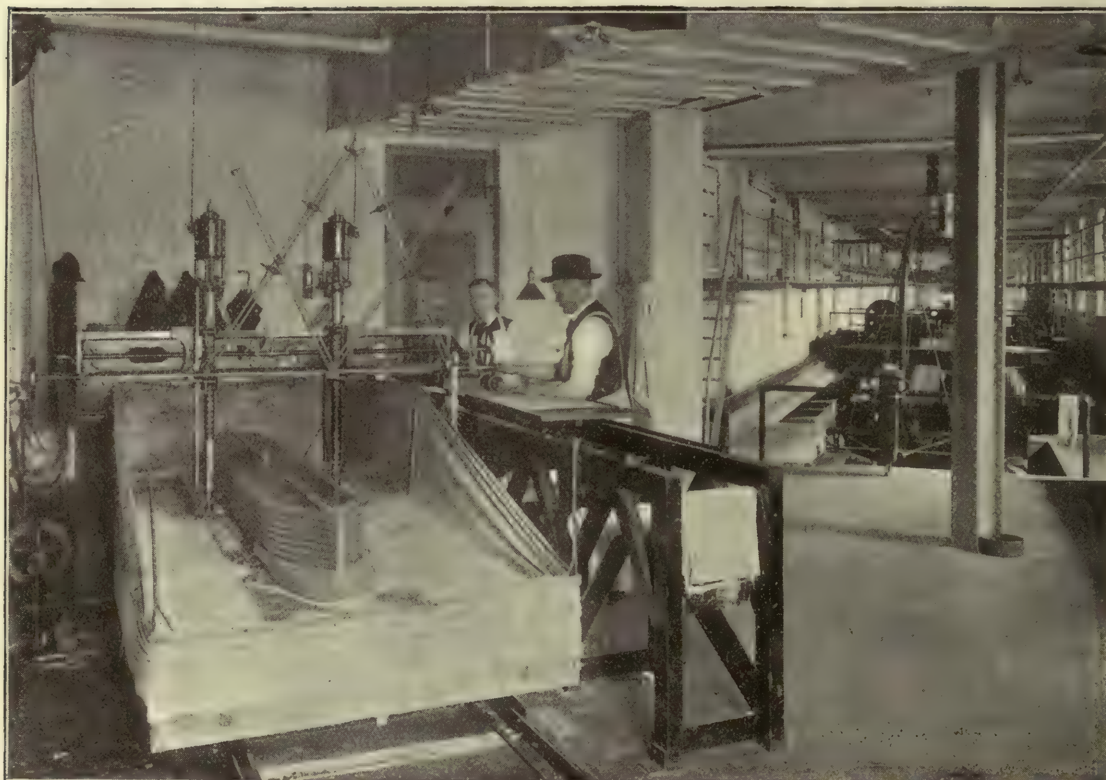


Fig. 1.—A MODEL OF A SHIP BEING CUT OUT OF PARAFFIN WAX BY A MACHINE FURNISHED WITH REVOLVING CUTTERS, WHICH MOVE TOWARDS OR AWAY FROM THE CENTRE LINE OF THE MODEL IN OBEDIENCE TO THE MOVEMENTS OF A GUIDE DRAWN BY THE WORKMAN ALONG THE LINES OF THE PAPER PLAN ON THE TABLE AT THE SIDE.

THE naval architect, when designing a new ship, must give careful consideration to a number of factors mutually dependent upon one another. These factors are the same, be the vessel a cargo "tramp," an Atlantic liner, or a battleship; but they vary in relative importance according to the particular purpose for which the ship is intended. By the fundamental law of hydrostatics known as the principle of Archimedes, the volume of water displaced by the under-water portion of a ship (or, as it is termed, her "displacement") has a weight equal to that of the ship herself, together with the "deadweight" being carried. By the expression "deadweight" is meant the fuel, cargo, stores, and other movable weights on board which do not form part of the vessel or her equipment. With the necessary displacement the naval architect, in designing a vessel, must also secure a good "freeboard"—that is, height of the vessel's side out of the water—in order

Factors in the Design.

to ensure seaworthiness and lessen the probability of foundering in bad weather at sea. In the case of British merchant vessels, the Legislature, as represented by the Board of Trade, has stepped in to prevent overloading, the result being a notable diminution in the quired. Some idea of the complexity of the problem will be gained by considering briefly what those other qualities are. Often the length or breadth of a proposed vessel is limited by considerations of dock and harbour accommodation, while more frequently a

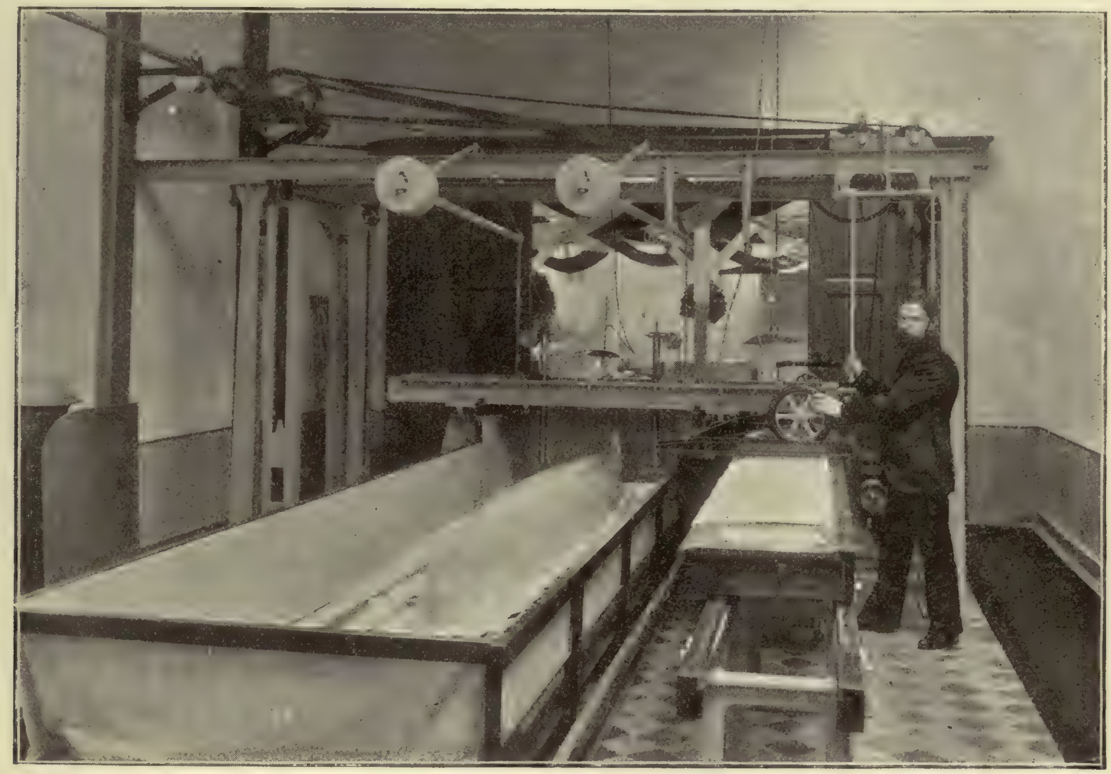


Fig. 2.—A COMPLETED WAX MODEL.

number of losses at sea. The primary consideration therefore in designing a new vessel is to provide displacement to float the ship and cargo, the freeboard being on no account less than that required by the Board of Trade.

The process of fixing the dimensions necessary for this purpose is a tentative one, successive consideration of the various factors involved requiring modifications and adjustments until the necessary equality between the displacement and the weight of the ship and cargo is attained, in conjunction with the other qualities re-

Choice of Dimensions.

governing factor is the limited draught of water available in certain ports. Apart from the question of carrying a certain weight of cargo, sufficient internal space must be provided to contain that cargo, supposing it to have the smallest density probable in the trade for which the vessel is intended. A similar factor enters into the design of passenger ships, in that sufficient deck area must be provided for the passenger accommodation. Further, the new vessel must have ample stability—that is, tendency to remain in an upright position; she must possess the requisite strength in conjunction with a suitable structural design and economy

in weight of material; and she must have a form which can be driven easily at the required speed.

Form of the Ship.

As regards form, vessels with sharp ends are termed "fine," and with blunt ends "full." To indicate the degree of "fineness" or "fullness," naval architects commonly use a ratio known as the "block" coefficient, which represents the relationship of the actual volume of displacement to the displacement of a rectangular box, having the same dimensions as the length, breadth, and draught of the ship

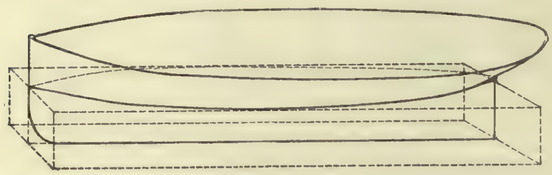


Fig. 3.—DIAGRAM TO SHOW THE MEANING OF THE TERM "BLOCK COEFFICIENT."

The coefficient is obtained by dividing the displacement of a vessel by the displacement of a rectangular box having the same length, breadth, and depth of the below-water part of the hull.

(Fig. 3). High-speed cruisers or passenger liners may be as fine as ·5 block coefficient, while low-speed cargo vessels may be as full as ·8.

It will perhaps be of interest at this stage to indicate how the displacement is utilized in typical vessels, as given in the following table:—

	Battleship.	Armoured Cruiser.
Hull	37 per cent.	40 per cent.
Armour	27 ,,	20 ,,
Armament	11·5 ,,	6 ,,
Machinery	12 ,,	20 ,,
Coal	6·5 ,,	9 ,,
General equipment	6 ,,	5 ,,
	High-speed Atlantic Liner.	**Low-speed Cargo Steamer.**
Hull and equipment	53 per cent.	25 per cent.
Machinery	27 ,,	4 ,,
Coal	16 ,,	5 ,,
Cargo	2·5 ,,	65 ,,
Stores, fresh water, etc.	1·5 ,,	1 ,,

Gross and Net Tonnage.

The terms "gross" and "net" tonnage, largely used for statistical purposes, represent the internal capacity of the ship as measured legally by the Board of Trade for payment of harbour dues, etc. *Gross* tonnage includes the capacity in cubic feet, divided by 100, of all enclosed spaces; while to obtain the *net* tonnage, deduction of the space occupied by the propelling machinery, fuel, and crew is made from the gross, so that the net tonnage may approximately be proportional to the earning power of the ship. It will be seen from the foregoing explanation that these terms do not show the weight of cargo carried.

Fig. 4

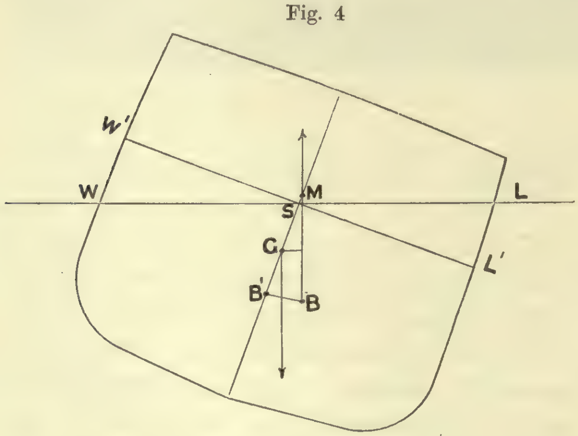
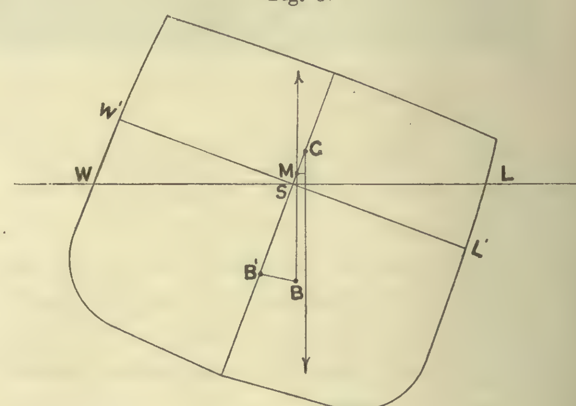


Fig. 5.



DIAGRAMS TO EXPLAIN THE TERMS "METACENTRE" AND "METACENTRIC HEIGHT."

The problem of stability will be better

understood by reference to Figs. 4 and 5. Suppose a vessel to be floating upright at

Stability.

the water-line W L, the upward force due to the displacement acts at the centre of buoyancy B^1. Now suppose the vessel to be inclined through a small angle W S W^1 (Fig. 4), the centre of buoyancy will move to B, and the vertical, through B, will cut the centre-line at M. If the centre of gravity, G, of the weight of the ship and cargo is below M, as in Fig. 4, a righting moment will be brought into play tending to make the vessel return to the upright—that is, the vessel is stable. Should, however, the point G be above M (Fig. 5), the moment is an upsetting one, tending to heel or incline the ship still further. The point M is termed the "metacentre," and the distance G M the "metacentric height," the latter being commonly referred to as a measure of the stability possessed by the ship. The metacentric height can be increased by adding to the vessel's breadth, and therefore raising the point M, owing to B moving further out for a given inclination; or by lowering the centre of gravity G, either by reducing the weight of the upper portion of the ship and cargo or by adding weight in the bottom. Care must be taken, in choosing a metacentric height, that a good "range" of stability—that is, maximum inclination at which the vessel remains stable—is secured. In this respect a good freeboard is very beneficial. Battleships require relatively larger metacentric heights in order that they may be stable with different compartments flooded, as might be the case when damaged by the enemy's fire, and it is for this reason that such a large breadth is adopted in this class of vessel.

Coming now to the problem of strength,

Strength.

the sizes or scantlings of the various parts of a ship's structure are largely the outcome of practical experience, which has been embodied in the rules of the great registration Societies—Lloyd's, Bureau Veritas, British Corporation, and other kindred institutions. Wood and iron, as already indicated, have of late years been superseded almost entirely by mild steel as the material for the structural portions. More recently a stronger variety of steel, known as high-tensile steel, of reduced scantling, has been employed in the construction of the upper portions of high-speed vessels, such as torpedo-boat destroyers, where economy in weight is of great importance.

Considered in the direction of length, the ship may be compared to a girder for which the supporting forces are not directly underneath the loads, especially when the vessel is among waves. Consequently, to secure adequate longitudinal strength without unduly increasing the weight of the structure, a suitable depth in relation to the length of the ship must be provided. All continuous longitudinal materials—such as the shell plating, deck plating, tank top or inner bottom, stringers, etc.—are considered to form part of the "equivalent girder." For purposes of com-

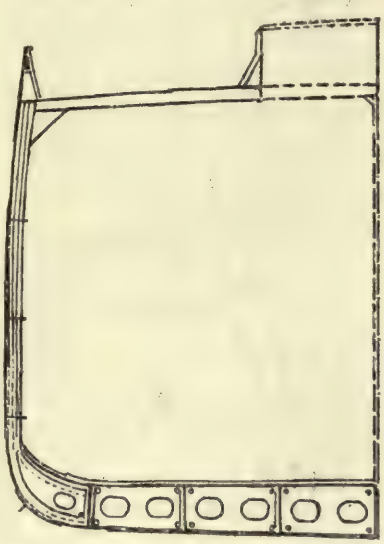


Fig. 6.—HALF SECTION OF CARGO STEAMER WITH TRANSVERSE FRAMING.

parison, stresses are calculated assuming the vessel to be (1) supported on the crest of a wave at the middle of her length with her

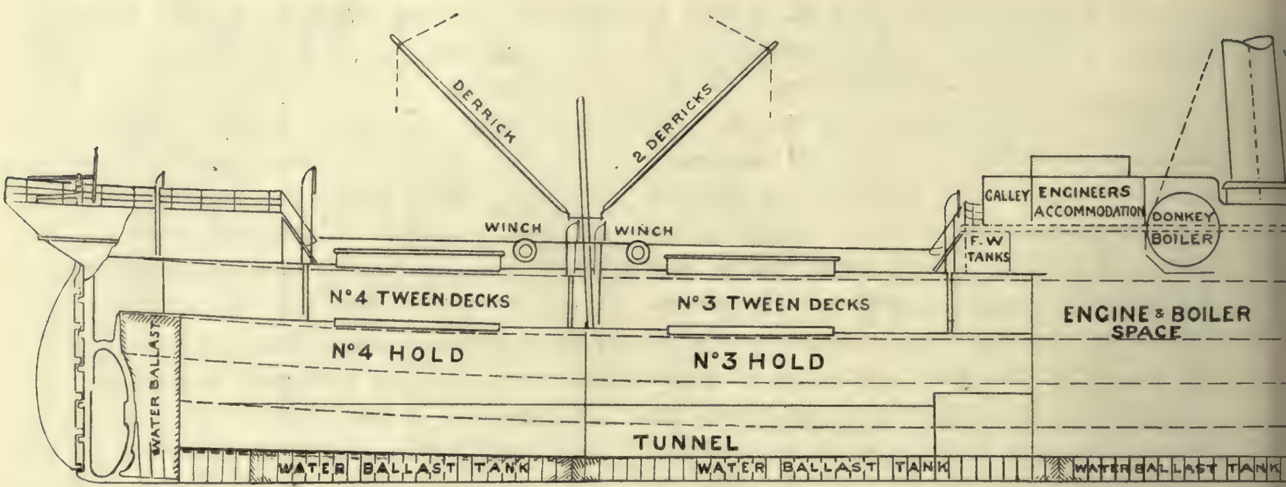


Fig. 10.—LONGITUDINAL SECTION OF CARGO STEAMER, SHOWING

ends unsupported; and (2) with the hollow of a wave amidships, and each end of the ship resting on a wave, the wave in both cases having a length equal to the ship's length and a height of one-twentieth of the length.

The distribution of longitudinal material will be seen from the comparative sections of the *Lusitania* and *Great Eastern* (page 318), and from Fig. 6, which illustrate the structural design of the Atlantic liner *Lusitania* and a cargo steamer respectively. It will be noticed how the "topsides" and deck are thickened up to form the upper flange of the girder (amounting to no less than 2 to $2\frac{1}{4}$ inches in the case of the *Lusitania*), while the bottom plating and tank top plating form the lower flange. The framing which supports the outer shell usually consists of transverse girders spaced not more than 2 to 3 feet apart. In passenger vessels, where numerous decks are required for the accommodation, the side frames are comparatively small. In cargo steamers, however, where large clear holds are essential, the intermediate decks or tiers of beams are dispensed with wherever possible, and larger frames, known as "web" frames and "deep" frames, are fitted. With the same object in view, various patented forms of ship have been designed during late years, of which the most widely adopted—Doxford's "turret" form—is shown in Fig. 7; while another type—Harroway and Dixon's cantilever framed ship—is shown in Fig. 8.

Structural Design.

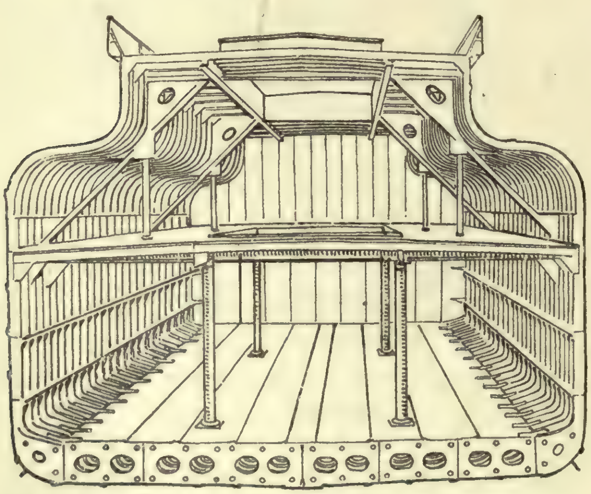
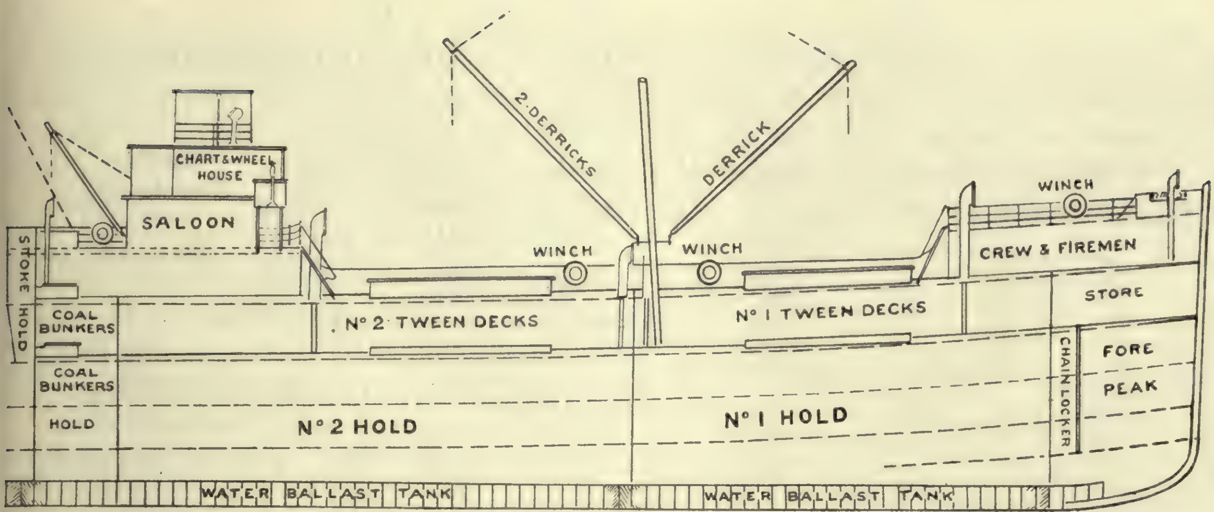


Fig. 7.—SECTION OF A DOXFORD "TURRET" FORM STEAMER, WITH LARGE CLEAR HOLD.

Various systems of longitudinal instead of transverse framing have been suggested at different times, a notable example of the application of this principle being, as already mentioned, the *Great Eastern*. Lately the system of longitudinal framing has been revived in the case of several cargo steamers—it is claimed with a considerable reduction



ARRANGEMENT OF MACHINERY, HOLDS, BUNKERS, ETC.

in the weight of material required. The arrangement recently adopted, known as the Isherwood system, is illustrated by Fig. 9, the

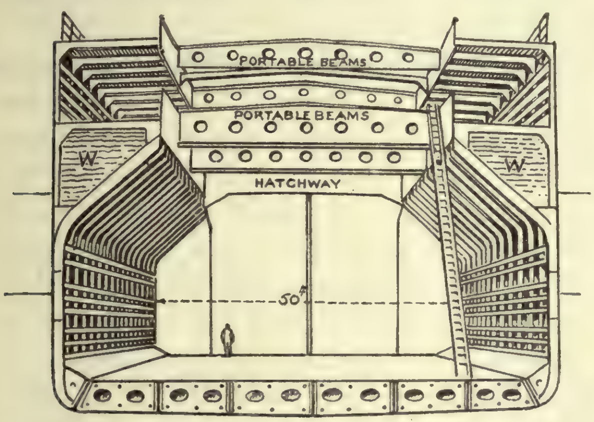


Fig. 8.—SECTION OF A CANTILEVER FRAMED SHIP WITH SIDE WATER-BALLAST TANKS, W W.

longitudinal framing being supported by deep transverse girders spaced about 12 feet apart.

General Arrangement.

The general arrangement of a steamship will best be understood by studying the most simple example—the ordinary cargo steamer, as shown in Fig. 10. To avoid difficulties with regard to trim—that is, difference in draught at the ends of the vessel—the propelling machinery is usually placed amidships, being divided from the cargo spaces by transverse water-tight partitions known as "bulkheads." Similar bulkheads divide the cargo spaces and shut off the end compartments, the function of the bulkheads being to limit the sinkage of the ship should the compartments be holed and laid open to the sea. In the highest class of passenger vessels the

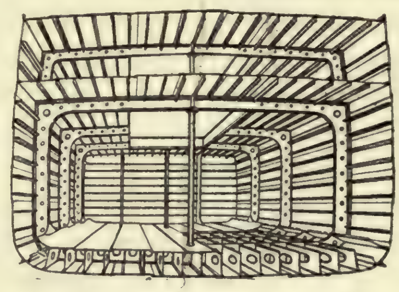


Fig. 9.—LONGITUDINAL FRAMED SHIP: CLEAR HOLD.

Board of Trade requires that they must remain afloat with any two compartments flooded—a provision which renders these ships practically unsinkable.

Another important question when designing a cargo steamer is the provision of ample water ballast capacity to give the vessel good immersion when making voyages without cargo. For this purpose a double bottom is usually fitted, which offers the additional advantages of increased longitudinal strength

and safety in the event of the vessel grounding. As, however, carrying all this weight in the bottom of the ship may render a vessel unduly stable and uneasy in her rolling, in some cases side ballast tanks have been fitted (M'Glashan's patent), as shown in Fig. 11;

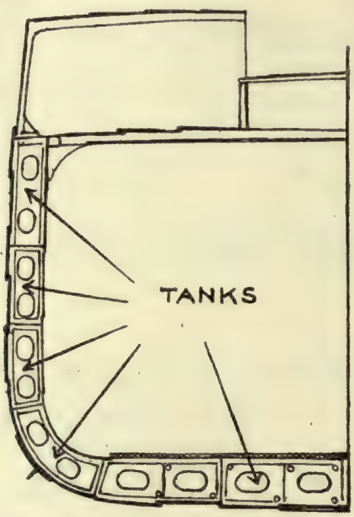


Fig. 11.—HALF SECTION OF SIDE TANK STEAMER.

while in the section shown in Fig. 8 triangular spaces at the corners of the deck are utilized for this purpose. As regards loading and discharging facilities, large hatchways must be provided in the decks, together with numerous winches, derricks, and cargo gear.

Cabin accommodation in a cargo ship is very simple, and presents no difficulties in design. Very different, however, are the requirements in the case of a passenger vessel. Here everything must be done to secure the maximum amount of comfort for the passengers. The arrangement of cabins and public rooms must facilitate decorative effect, and due attention must be given to the problems of ventilation, lighting, heating, cooking, water services, and other subsidiary matters too numerous to mention. In the case of warships, paramount interest centres in the provision of efficient armour and armament, in conjunction with high speed and the carriage of sufficient fuel to give the vessel a good radius of action.

Speed, Resistance, and Propulsion.

The problem of speed involves, in the first place, consideration of the "resistance" of the ship. This is due to two causes—"skin friction" and "wave-making." Frictional resistance is the result, as its name implies, of the rubbing of the particles of water against the vessel's skin, while wave-making resistance is due to the formation of wave systems at the bow and stern. Various formulæ have been proposed for determining ship resistance, but all are more or less based upon the trials of existing ships; and the only reliable method of determining the resistance of a new design with any certainty is the experimental tank method devised by the late Mr. W. Froude, to whom—in conjunction with his son and successor at the British Admiralty tank, Mr. R. E. Froude—our present knowledge of this subject is chiefly due.

In addition to that owned by the British Government, experimental tanks have been constructed by several foreign states, and also by two private shipbuilding firms in the United Kingdom—Messrs. William Denny and Brothers of Dumbarton, and Messrs. John Brown and Company of Clydebank. A view of such a tank is shown in Fig. 12. It will be observed from this illustration that a recording carriage is provided, which travels over the tank and for its full length, the model being attached beneath the carriage. The models are shaped out of paraffin wax by a special cutting machine, their length being 12 to 15 feet. The records obtained by towing a model at different speeds can be applied to any ship of the same form and proportions, no matter what her absolute dimensions may be.

After determining a ship's resistance, the next question to be decided is a suitable value for the *propulsive coefficient*—that is, the ratio of the power usefully employed in overcoming the ship's resistance (or, as it is termed, the *effective horse-power*) to the power

Fig. 12.—THE NEW MODEL TESTING TANK AT WASHINGTON.
The Model is attached to the electrically moved Carriage spanning the tank.

given out by the engines, known as the *indicated horse-power*. Its value rarely exceeds ·5, or, in other words, the effective horse-power (E.H.P.) is seldom more than half the indicated horse-power (I.H.P.), as the I.H.P. must include, besides the E.H.P., the power necessary to overcome the friction of the engines and that absorbed by the propeller, mainly owing to the "slip" of the latter. By "slip" is meant that the propeller, owing to its not working in a solid medium, moves at a greater speed than that at which the ship is driven forward, and consequently imparts sternward velocity to a large quantity of water, with a necessary absorption of power in the process.

The design of a suitable screw propeller, if a high speed is desired, is a very difficult problem. This, again, is best attacked with the aid of the experimental tank, although a disadvantage of tank work is that the model and the screw must be tested separately. For this reason it was considered advisable, when designing the Cunard liner *Mauretania*, to construct a self-propelled electric model launch, 47½ feet long, having the exact form of the ship, and driven by model propellers. But for the expense involved, this certainly appears to be the most reliable method yet devised.

Rolling in a Seaway.

With regard to rolling in a seaway, the naval architect, after satisfying the claims already referred to, has generally little latitude to effect changes in the form or dimensions in order to reduce rolling, and must rely mainly on external appliances, such as a centre keel, bilge keels, etc. Steadiness at sea is, of course, highly desirable in the case of passenger vessels, in order to reduce

Fig. 13.—MAKING A TEST.

The men on the Carriage are watching, by means of instruments, the behaviour of the Model in the tank below.

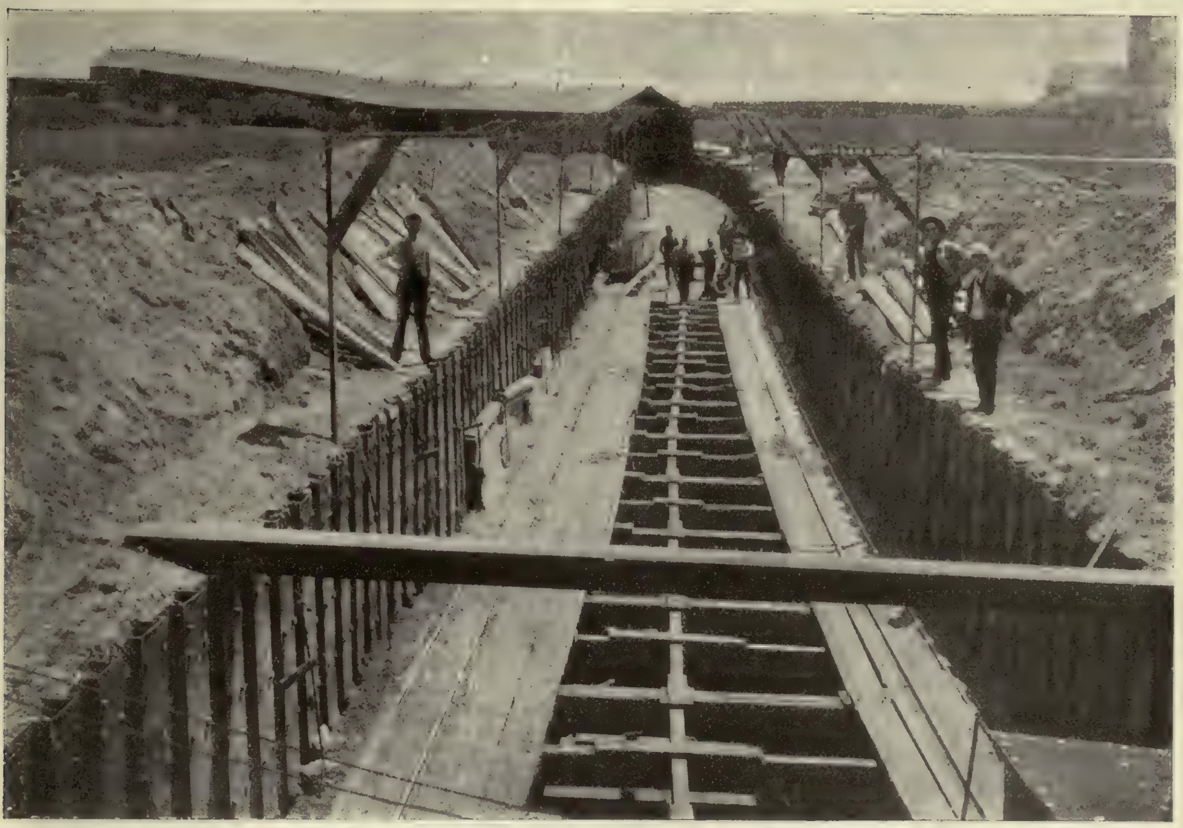
sea-sickness, and in warships also a minimum rolling motion is essential to secure a steady gun platform. The most important factors in providing steadiness are a comparatively small metacentric height and distribution of the heavier weights far from the axis about which the ship rolls. Fortunately, this condition of affairs exists in the case of most large passenger vessels, and Atlantic liners, having metacentric heights of from 15 to 18 inches, have proved remarkable for their steadiness. Owing to the extra draught of water required for a centre keel, it is now the usual practice to fit keels at the bilge instead of a centre keel, and experience has shown the efficiency of these bilge keels, especially in vessels having a very round bilge.

A new method of preventing rolling has recently been devised in the Schlick *gyroscope*, which has been tried with great success on board an experimental vessel, and on the passenger steamers *Silvana* and *Lochiel*, the latter one of Messrs. MacBrayne's vessels plying on the west coast of Scotland; and its application appears to offer great possibilities for the smaller classes of passenger vessels and warships.

Such are, briefly, some of the main factors the naval architect has to consider in designing a new ship; and, needless to point out, they could be greatly enlarged upon if space permitted. Enough has been said, however, to show that the designing of a ship is one of the most comprehensive and difficult problems in the field of applied science.

THE UNDERGROUND FREIGHT RAILWAYS OF CHICAGO.

This Article describes how the City of Chicago has relieved its Street Traffic by the construction of Subterranean Railways for carrying Goods and Mails.



OPEN CUT WORK FOR SUBWAY INCLINE TO SURFACE AT GREAT PARK.

WHILE London, New York, and other large cities have been busy building and extending their subterranean railway tracks to accommodate the ever-increasing travelling public, Chicago has been quietly constructing an underground railway for the express purpose of carrying its freight. On this unique system not a single passenger is transported—only goods and mails. Far below the surface of the street electric locomotives are busy day and night hauling thousands of tons of merchandise, mails, coal, ashes, garbage, and *débris*, without noise, without dirt, doing the work well and expeditiously. When it is stated that there are now some 60 miles of track in operation, covering the whole of the business district of the city and the greater portion of the principal residential quarter, it will be understood that this is no ordinary railway enterprise, but one designed to meet some special need, and for that reason it is well worthy of notice.

Chicago, owing to its topographical forma-

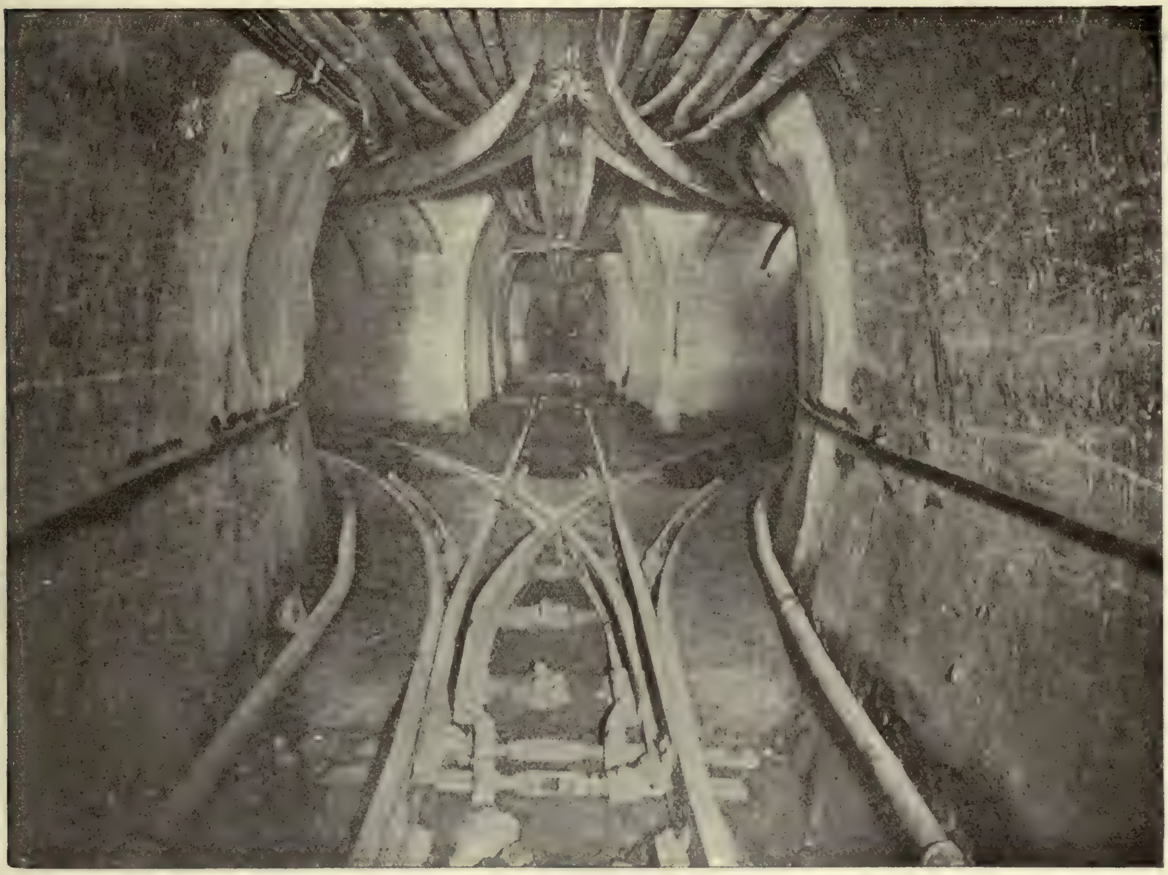
tion, found its freight traffic congested more than its passenger. With no fewer than twenty-five trunk lines running into the city, Chicago's freight tonnage traffic is enormous, and this is confined within a comparatively small area—not more than a mile and a half square. In this district teamsters' trucks and wagons constantly block the way—or rather did so before the advent of the underground railway, and caused such congestion of traffic that business was often paralyzed for hours at a time. The city authorities were at a loss to know what to do. It was impossible to change the termini of the trunk lines, and the traffic was doubling itself every decade. For two years or more the municipality discussed ways of relieving the condition of the streets, but, as often happens, it was left to private enterprise to find a solution—in the construction of a freight subway.

The Need of the System.

Imagine for a moment what such a railway would mean to London, or to any other large city, and you may grasp how it has virtually revolutionized the street traffic of this western American city. All the goods and parcels for a great warehouse would be delivered right into its basements by the underground railway having connections with the leading railway depôts. In the same way the various post offices would send their mails from one office to another by this route. The great stores would deliver a large portion of their goods by the subterranean road; while all the coals for the hotels on the line of route would be conveyed to them by rail, and the ashes and garbage removed in the same expeditious manner.

FOUR-WAY INTERSECTION AT DEARBORN AND WASHINGTON STREETS.

The construction of a network of lines far below the surface of a city's streets is in itself a difficult feat, but in the case of Chicago the engineering problems to be overcome were of the most perplexing character. The city is built on a vast deposit of soft clay, of a consistency resembling that of cheese. Heavy buildings have to be supported on piles or concrete piers, which pierce this clay until they finally reach bedrock, from 80 to 120 feet below the street level. The weight of many of these buildings is enormous; and while it was not contemplated that the tunnels should go under them, but under the middle of the streets on which they abutted, there was a possibility that the removal of the amount of material necessary for the bores through the centre of the street, and the tremendous weight resting on each side, might lead to settling and straining of the buildings, or even total collapse. How real this danger was the construction of the New York Subway demonstrated at a later date, when several buildings were entirely wrecked because of the excavations in the street which they faced.



TYPICAL STREET INTERSECTION.

Observe the peculiar arrangement of double points.

It is one of the most astonishing facts in the history of the Chicago Tunnel construction that, though the work lasted seven years, though every street in the business section of the city has been tunnelled, and some 60 miles of subways have been constructed, there has not been a single claim for damages on the part of any property

owner. There certainly have been settlements, or supposed settlements, along the route, but experts competent to judge have declared that these subsidences were not due in any way to the construction of the tunnels. Again, it is gratifying to record that in the erection of the subways no lives were lost. In a report recently issued by Mr. George W. Jackson, the general manager and chief engineer, reference is made to these points as follows : " So many misleading, malicious, and vicious reports have been circulated about damages being done by this Company's work, that I feel it my duty to state emphatically that the construction of the entire system has been accomplished without the Company being called upon to defend or pay any claim for damages of any kind. No deaths have occurred that can be attributed to tunnel construction, and not one employee has been disabled to such an extent as to prevent him from following his usual vocation." Another interesting fact about this unique undertaking is that the capital of £10,000,000, required to build the subterranean freight road, was subscribed privately, no stocks or bonds being offered to the public.

No Settlements of Ground reported.

As a matter of fact, the work was done so quietly that very few people in Chicago itself realized what had happened until the newspapers announced that a wonderfully complete and up-to-date underground railway system had been built under its streets, and would shortly be opened for traffic. This was not because the engineers went about their task in secret and purposely avoided publicity.

The original promoters of the scheme were the owners of a telephone company, known as the Automatic. The most striking features of this telephone are that it does away with operators at the central station, that a subscriber calling up another subscriber is able to make his own connection, and that when two persons are talking together over the wires it is impossible for a third to " butt in " or listen to the conversation. Mr. Albert G. Wheeler, the engineer for this particular Company, who really planned and carried to a successful issue the tunnel subways, when making an application to the City Council for a franchise, made it for the Illinois Tunnel and Telegraph Company, now known as the Illinois Tunnel Company. If anything was said before the City Committee about the subject of handling *freight* in the tunnels it was merely incidental, and excited no particular interest. The franchise, as granted eventually, specified that the tunnels were to be constructed and used for the transmission of " sound, signals, and

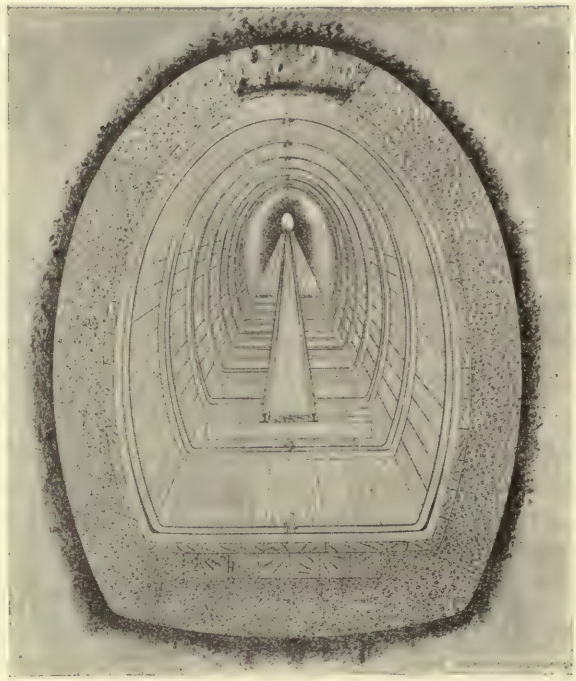
Telephones and Tunnels.

A LOADED FREIGHT TRAIN ROUNDING A SHARP CURVE AT AN INTERSECTION.

intelligence by means of electricity or otherwise." The distribution of newspapers or letters, for instance, comes under the head of "intelligence," but one would not expend millions in building a tunnel system for the purpose of handling one paper or one letter. Papers and letters must be treated in bulk and as freight. All that the authorities stated at the time was that the tunnels were to be made high and wide enough for a man to work in comfortably, with ample space for the suspension of the telephone wires from the roof and side walls, and planned to meet the future growth of the system. They also stipulated that the subways were to be some 40 feet underground. This was an exceedingly wise condition, as it permits the construction, should it ever be needed, of a tunnel for passenger trains between the street level and the subways, the floor of the latter being 46 feet below the surface.

Having obtained permission, the engineers commenced operations. The first thing was to survey the line of route. Every street in the business section of the city was surveyed thoroughly, the engineers refusing to accept the existing maps, many of which were found to be faulty. As observations could not be made on week-days, when the streets were choked with traffic of every description, the work had to be done on Sundays. For the sake of speed and economy, it was necessary to operate from several widely separated points simultaneously. At each of the points selected a shaft was sunk to the tunnel level, and drifted out to the centre of the street, whence excavation was begun in both directions on the axis of the tunnel. Most of these shafts were sunk in the basements of buildings rented by the Tunnel Company, and fitted up as workshops. Here concrete was mixed and lowered to the tunnels, and air-compressing machinery was installed.

Surveying the Streets.



METHOD OF TUNNEL CONSTRUCTION.

This figure shows the steel channel ribs supporting the 2-by-6-inch lagging boards, between which and the ground concrete is rammed tightly in. As soon as the concrete is set, the centres and ribs are removed.

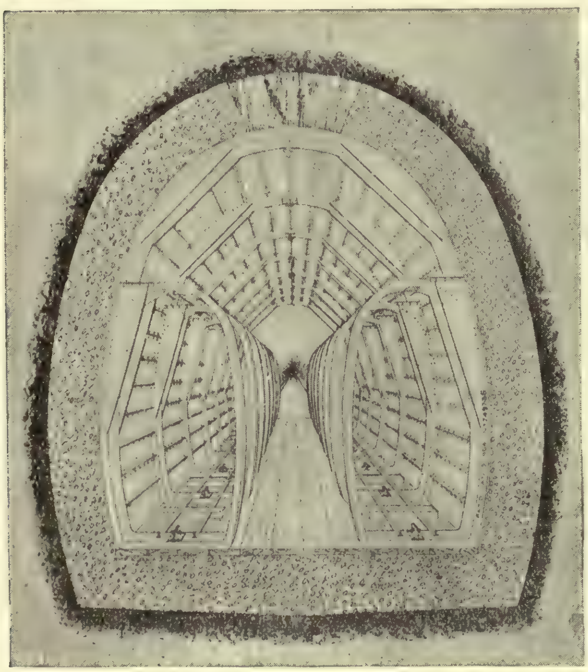
The tunnels are of two distinct types—trunk tunnels and lateral conduits. The former follow the main routes of freight traffic. The latter run out to the less important parts of the city, and in time will reach the suburbs, and end in small conduits adapted only to accommodate telephone and other wires. The main or trunk line tunnels are 14 feet 6 inches from crown to floor, and 12 feet 9 inches wide at the base; while the laterals are 7½ feet high and 6 feet wide. The trunk subways have 18-inch cement walls and 21-inch cement floors; the smaller tunnels 10-inch walls and 13-inch floors. At the top and sides of these subways are strong cables containing telephone wires, while the floors are left free for freight traffic.

Active excavation began on September 1, 1901, and by November 1904 twenty miles of track had been laid and made ready for use. An ingenious system of excavation was

adopted as affording a safeguard against labour troubles. In this system there can be no possibility of "caving in" or collapse should a strike occur and workmen be unobtainable. A description of the plan followed in the building of the 6-by-7½-foot conduits will give an idea of how the excavations were made and the concrete subway installed.

Building the Subways.

The bore in the clay was dug considerably larger than the dimensions of the finished subway. The mining was done by men with hand tools, the material being removed subsequently by mule teams. After the excavators had finished their labours the cementing gang appeared. Their first task was to place in the bottom of the tunnel the required layer of concrete, tamp it thoroughly, and lay on top of it a lagging of boards. This done, they placed at intervals of three feet steel ribs of the size and shape of the inside of the tunnel. When these ribs were in place, a lagging of 2-inch planks was placed between them, and concrete packed in behind the lagging in layers of six inches, so as to fill up the entire space between the wood and the walls of the excavation. In this way subsidence of the ground was avoided, because, no matter how irregular was the mining, every void was filled. This method was followed to the top or key of the arch, where, to ensure absolute accuracy, the key-blocks were formed of lagging boards only three feet long, the use of the short section ensuring better work. After the ribs and lagging had been removed, the concrete was given a facing of cement to seal all crevices.



STEEL RIBS AND LAGGING USED IN FORMING CONCRETE LINING OF A 12-BY-13-FOOT TUNNEL.

In the larger, or trunk, lines a somewhat different process was followed, steel lagging plates being used instead of planks, and 5-inch instead of 3-inch channel irons for ribs. The work was done in sections only three feet long, the steel lagging plates being of just sufficient length to span the 3-foot sections of the ribs.

The tunnelling was effected by three shifts of men working eight hours each, the first two shifts doing mining work and the third shift concreting. About 850 men were engaged in the three shifts. In this way the tunnel was mined and cemented at the rate of more than 300 feet per working day, or considerably over a mile a month. More than 300,000 cubic feet of material was excavated in a period of three years, and about half that quantity of stone, cement, and gravel was put in place. As many as thirty-eight connections had to be made between different tunnels, and so accurately was the surveying done that in no instance was a junction an inch out of truth. An air pressure of about 8 lbs. to the square foot was maintained throughout the tunnel during the construction period, this being found sufficient to prevent the water from encroaching as the work progressed.

How the Work progressed.

The excavated material was removed in a novel manner. At various points along the

street "head houses" were erected. Here the loaded cars from the tunnel beneath were brought up through vertical shafts, and their contents were dumped into wagons to be transported to the lake front. This carting of the material through the streets of the city was done at night only. The dirt was utilized for reclaiming nineteen acres from the lake and adding them to the city's park, without one cent of expense to the park authorities. The Tunnel Company now run cars to the surface at the "dump" by means of an inclined railway connecting with their system.

Wherever a big building has been erected in Chicago during the past two years the subway has been employed to haul away the material excavated from the foundations. This is accomplished by simply running up from the tunnel to the excavation a shaft about three feet in diameter. The workmen wheel their barrows of soil to the yawning mouth and empty them into it. As these shafts make an angle of about 45 degrees with the horizontal, gravity carries the *débris* to the bottom, where it falls into a waiting car. One car filled, another is moved under the mouth of the chute, and when a train has been made up an electric locomotive hauls it away to the lake front. By this method the subway has moved from the basement of one building alone 2,100 cubic yards of material in twenty-four hours. The best record by teams in the same time is 420 cubic yards, and to do this even it was necessary for the contractors to stop their overhead work entirely.

Removing Excavated Material.

As already stated, when the system was declared open in November 1904, 20 miles of lines had been laid. By September last the mileage had increased to just over 60. Naturally, the greatest revenue from the operation of the tunnels comes from the transportation of freight. There is more freight hauled through the streets of Chicago than through those of any other city of America. New York hauls about 75,000 tons of freight daily, Philadelphia and Boston about 65,000 tons each, Chicago 100,000 tons. The underground railways do not expect to move all this freight, but are prepared to take one-third or more of it if they can get it. This branch of the business is now being pushed forward energetically, but the authorities have had to educate the merchants and manufacturers to the advantages of the subways. First of all they offered to install, free of charge, in any of the large warehouses and stores along their route, special shafts and elevators, to connect these establishments with the subterranean railway. The first fifty installed cost £200,000. But these houses find them invaluable. The cars of the underground system bring goods direct from the railway depôts to the basement of the buildings, whence elevators raise them to the desired floor. Of course, this direct connection between tunnel and warehouse is not always possible, so the railway authorities have built central depôts at various places throughout the city, so that a shipper is not obliged to haul his merchandise more than a few hundred yards.

Direct Connection with Warehouses.

Two years ago the subway officials secured from the postal authorities a contract for the transportation of the mails. This contract was obtained only by convincing the powers that be against their will of the advantages offered by the new system. The main post office building in Chicago is the heaviest edifice in the city, and its enormous weight is supported on piles driven down to bedrock. When the engineer first approached the postal officials with a proposition to connect the building with the tunnel system, so that the mails might be

Carrying the Mails.

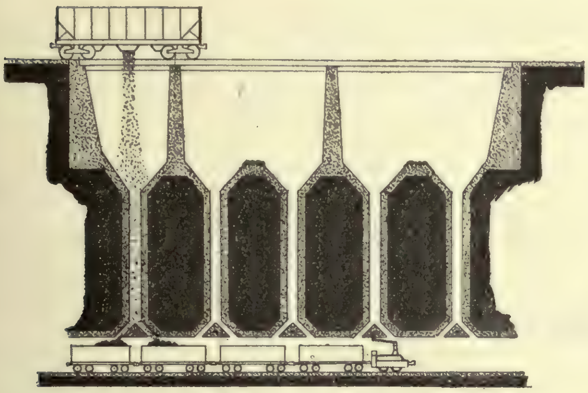
carried from one office to another underground, they scouted the idea, saying that any such connection would undermine the building, cause a settlement, and probably result in its entire collapse. To prove that they were wrong, the engineer constructed a subway right under the centre of the structure. In places this tunnel had to go through the piles on which the building rests, and the result is that the subway actually rests on the bottom portions of these piles, and the top parts of the piles on the crown of the tunnel. After this work had been completed, the engineer invited the postal officials to take a trip through the tunnels as his guests. They accepted the invitation, and one can imagine their surprise when the car was suddenly stopped, and they were informed that they were then right under the post office building. For two days, it is said, the leading surveyors of Chicago were busy examining the edifice critically, but could not find a crack or a piece of plaster that had been disturbed. The post office still rests as solidly on its foundations as does the rock of Gibraltar. Not long afterwards the tunnel people secured the contract spoken of.

MAIL BAGS BEING TRANSFERRED FROM THE CHICAGO POST OFFICE TO THE SUBWAY.

For this mail work the railway employs 66 electric motors and 115 cars. In 1907 the electric trains made 337,060 trips with mails through the subways to the various branch offices, railway stations, etc., transporting 10,659,567 bags, pouches, and packages of postal matter. The record for this tremendous service was "99·51 per cent. perfect"—that is to say, in this proportion of cases the mail was delivered at the proper stations in time. Last Christmas Eve the Company handled, without a hitch, 44,341 bags of mails, 5,911 pouches, and 195 packages—a total of 50,447.

In the construction of the tunnels the Company has burrowed under the river in fourteen places. Its lines now reach from Armour Avenue and Archer Avenue on the

BELT CONVEYOR DISCHARGING MAIL BAGS FROM SUBWAY ON TO PLATFORM AT THE UNITED STATES POST OFFICE, CHICAGO.

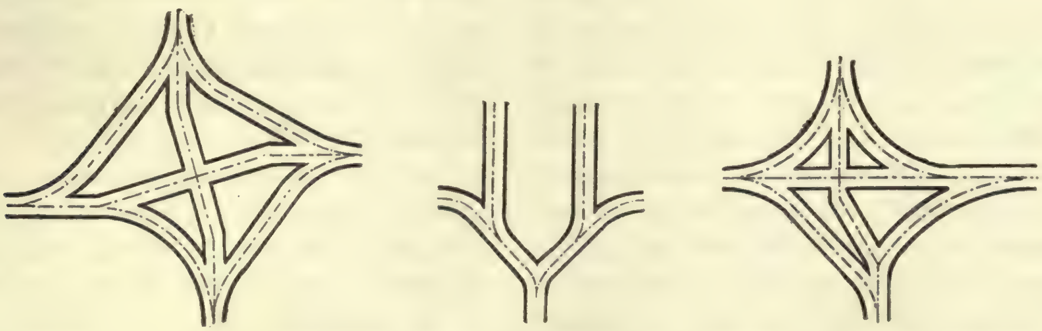


HOW COAL IS TRANSFERRED FROM A SURFACE LINE TO SUBWAY TRUCKS.

south to Chicago Avenue and Kingsbury Street on the north, and to Green Street on the west. The equipment consists of 250 motors and 2,500 cars; but, of course, these are added to as needed. Both engines and cars are of a special pattern. The locomotives are of the class used in mines, and have a wheel base of 24½ inches. Two sizes of engines are employed—the smaller one boasting 75 horse-power motors and weighing about 3 tons; the larger ones being of 80 horse-power, and turning the scale at about 5 tons. The cars, 4 feet wide and 10½ feet long, reach 63 inches above the rail. Their individual capacity is 30,000 lbs. They are of iron and steel construction, with double trucks and eight wheels. The gauge of the lines is 2 feet. The steepest grade in the subways is 1·75 per cent., and the gradients at the railway terminals do not exceed 12 per cent. The latter grades form the approaches to the tunnels. The largest intersections, known as four-way sections, where the track branches off in three directions, have curves of 20-foot radius. The curves on the main lines, however, are of 16-foot radius. There is a complete drainage system. A telephone station on every block enables the movements of the trains to be controlled entirely by telephone. The whole subway is lighted electrically, and has a twenty-four-hour service.

Extent of Subways and Equipment.

To-day the subways are owned by a corporation in which railway interests are largely represented. High praise is undoubtedly due to Mr. Albert G. Wheeler, the engineer who conceived and carried to a successful completion this remarkable and interesting underground freight road; and also to his able lieutenant, Mr. George W. Jackson, the general manager. Recently Mr. J. Ogden Armour and Mr. E. H. Harriman joined the board of the Illinois Tunnel Company. The presence of Mr. Armour, whose interests and name are so intimately associated with all that makes Chicago a synonym for enterprise, is in itself a guarantee that the best interests of the city will be served by the Tunnel Company. Coupled with that of Mr. Harriman, who is recognized in railway circles to-day as one of the greatest living constructive geniuses and financial managers on the American continent, the success of the subways seems to be assured.



PLAN OF TYPICAL INTERSECTIONS.

THE CONQUEST OF CHAT MOSS.

A Notable Feat of Railway Engineering.

WHEN, in 1821, George Stephenson and his friends projected the second railway ever built—that from Manchester to Liverpool—they had to overcome the opposition of powerful forces banded against them—the owners of stage-coaches, canal companies, great landlords—and to spend large sums of money before a Parliamentary Act sanctioning the construction of the railway was obtained. The route surveyed by Stephenson and finally adopted ran across a large peat-bog on the right bank of the river Irwell, a few miles west of Manchester. Like other bogs, the Moss had a surface of an exceedingly treacherous character, over which a man could not walk with safety. In fact, one of the surveyors nearly lost his life while using his instruments on the Moss. This particular morass extended for miles, and had a depth in places of thirty feet or more. In wet weather the mass of decayed vegetation sucked in water like a sponge, and swelled until the surface at the centre stood several feet above that at the edges, while in dry seasons it became slightly basin-shaped. Opponents of the railway were not slow to make full use of the help given to their case by the existence of the bog. "The making of an embankment out of this pulpy wet moss," urged counsel for the opposition while the Bill was in Committee, "is no very easy task. Who but Mr. Stephenson would have thought of entering into Chat Moss, carrying it out almost like wet dung? It is ignorance almost inconceivable. It is perfect madness, in a person called upon to speak on a scientific subject, to propose such a plan." A civil engineer of twenty-two years' experience gave it as his opinion that no railway could be carried across the Moss without going to the bottom, unless a solid embankment were built up from its bed, at an estimated cost of £270,000.

The Moss.

Stephenson, however, thought quite otherwise. As snow-shoes will prevent a man sinking into soft snow by distributing his weight over an area much larger than that of his feet, so, he argued, would a railway track be borne up on the bog if it rested on a platform of sufficient size. What the conditions required was to cast into the morass large quantities of heath and branches of trees to form a huge mattress which should practically float on the quaking mass beneath. He had not the least intention of building an embankment up from solid ground. His faith in his own method seems all the more remarkable when we remember that railway building was then in its earliest infancy, and that he had no precedents to follow, such as exist in plenty for the engineer of to-day.

A Huge Mattress.

The first operation in connection with the creation of the projected raft was to form a footpath of heather across the Moss on the line of the route selected, for the convenience of the workmen. This was added to until sufficiently buoyant to bear a light, temporary

narrow-gauge railway to transport the materials required for the permanent road. If any one strayed from this narrow belt he was likely to sink up to his middle in the quagmire.

To aid the consolidation of the track, parallel drains were cut along each side of the site of the permanent way to extract the water from the intervening mass. The consistency of the material in which they were cut caused these drains to close up almost as fast as made, and it was necessary to reopen them continually. At some peculiarly bad places permanent drains were formed of old tar barrels, laid end to end after their heads had been knocked out. Upon the surface between the drains the navvies spread heather, grass, hurdles, branches of trees, and cakes of dry turf. Near the Manchester end of the bog, where the ground was particularly bad, progress was extremely slow. Thousands of loads of dry moss were tipped to form an embankment, which, when it had attained a height of a few feet above the general level, would suddenly be engulfed. This happened repeatedly, and the only visible advance seemed to be confined to the totals of the wages bill. In several weeks the engineers had to report that their efforts were apparently wasted, and that they seemingly lost rather than made headway.

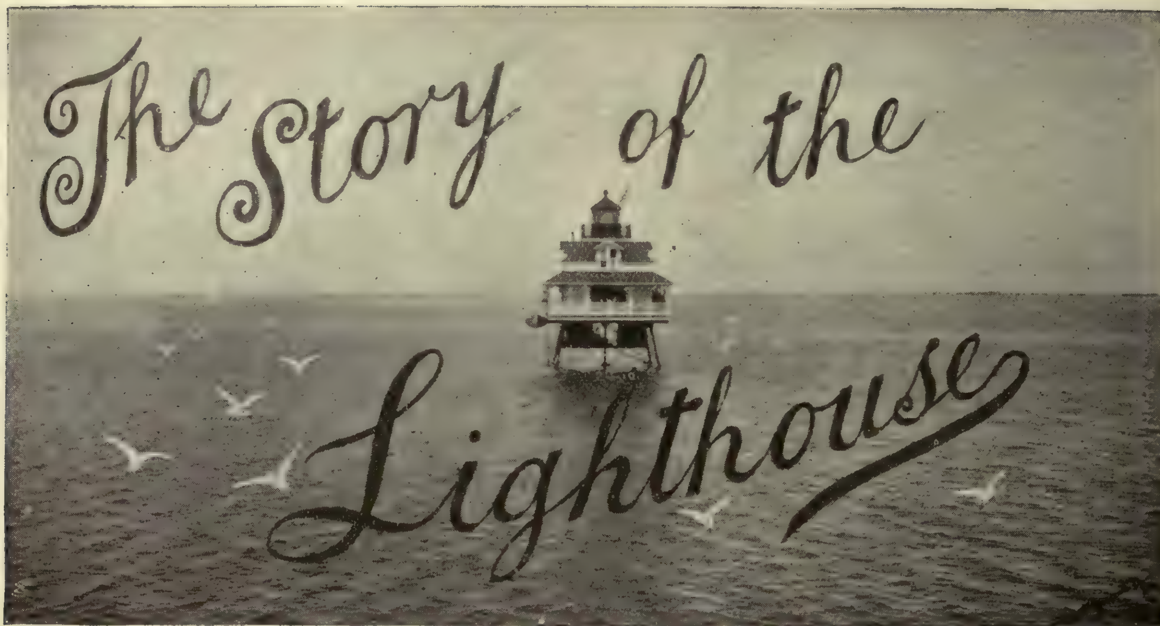
Stephenson's Faith.

The directors of the Company very naturally became alarmed by the state of affairs, and debated whether they should go to the expense of driving down piles or making a solid embankment, or should abandon the route for one avoiding the Moss. Investigation showed that the expense of a solid road-bed would be prohibitive, while to abandon the whole works and start new ones would also cripple the undertaking. Men who had spent their lives in the district prophesied that Stephenson's method must prove abortive, and that to persist in it would be to throw good money after bad. Dark indeed would have been the prospect but for Stephenson's heroic optimism. They must go on as they had begun, he urged. Though lost to sight, the material dumped was taking effect, as would soon become apparent. Hundreds of men and boys were set to work to skim the dry surface off the Moss for a mile around, and pile it up where needed ; and at last this very Slough of Despond was vanquished, though not until some 670,000 cubic yards of turf had been used. The permanent way was laid as soon as all signs of further subsidence ceased, and on New Year's Day of 1830 the famous "Rocket" steamed across the Moss, dragging a passenger train behind it.

Complete Success.

While the struggle between man and morass was in progress many rumours were circulated —drivers of stage-coaches being especially industrious as the bearers of bad news. At one time the Moss had burst upwards and engulfed men and horses wholesale. At another, Stephenson had disappeared into the depths, and the work had been abandoned. Despite the enormous difficulties to be overcome, this section of the railway cost less per mile than any other section, and in practice the theoretical £270,000 dwindled to £28,000, or very little more than the cost of getting the Railway Bill through Parliament. The road-bed obtained is not merely perfectly safe, but by virtue of its slight elasticity gives easy and smooth running.

The conquest of Chat Moss was one of the most notable achievements of the father of railways, and afforded a precedent which has since been followed in many parts of the world with equally good results. We may instance the Cockwood section of the Great Western Railway in South Devon, which crosses an unfathomable swamp. Truly, George Stephenson was a man of genius !



BY W. NOBLE TWELVETREES, M.Inst.Mech.E.

TO all maritime nations, and especially to the peoples of the Anglo-Saxon race, the subject of lighthouses possesses supreme interest. The present-day lighthouse, with its gracefully proportioned tower and beautiful equipment, is the modern representative of those lofty beacons which were erected, ages ago, near ancient harbours to guide the mariner home or to warn him of perils unknown beneath the face of the waters. The Greek word "Pharos"—a lighthouse—which has successively found its way into many European languages, was derived from the island of Pharos, at the mouth of Alexandria harbour, in Egypt. The tower, built there by Sostratos in the reign of Ptolemy II., was justly regarded by the ancients as one of the wonders of the world. It rose to the height of 590 feet, and, although threatened more than once, part of the tower remained erect after two great earthquakes in the fourteenth century, but was soon afterwards washed away by the sea, having bravely withstood the elements for more than two thousand years.

The Pharos of Alexandria.

In the early days of which we write, the warning gleam from the summit of a pharos proceeded from an open fire of wood, a material of illumination which was almost universally employed until the beginning of the seventeenth century. Even the South Foreland lighthouses, built in 1634, remained until 1790 mere beacons lit by burning coal, and the first instance of illumination by oil lamps and efficient reflectors was furnished in 1763 by the Mersey lights of Liverpool.

Early Modern Lighthouses.

So we see that, while sound and enduring construction was inherited from ancient days, so also were crude and inefficient methods of illumination, the evolution of the lighthouse as we know it to-day being the outcome of the scientific awakening which commenced with the past century.

Winstanley's Eddystone Lighthouse.

As an introduction to the principles governing the construction of lighthouses exposed to the waves, we may appropriately cite the tower erected by Winstanley on the Eddystone Rocks as an ingenious defiance of common sense, and a most excellent illustration of how things ought *not* to be done. (See Fig. 1.)

As finished in 1698, the tower was 80 feet high, and polygonal in form, thus presenting unnecessary obstruction to the action of the waves. Moreover, it had windows and projecting structures in the lower part, and at a distance of less than 40 feet above high-water level the tower began to assume the aspect of a bandstand or a Chinese pagoda, a configuration distinctly inviting the waves to lift off the upper portion. In 1699 it was found necessary to strengthen the tower by an outer sheathing of masonry and to increase its height to 120 feet. Nevertheless, in 1703 the structure was washed away during a great hurricane, and on its site was built, in 1704, the timber-framed lighthouse of Rudyerd (Fig. 2), destroyed by fire in 1755.

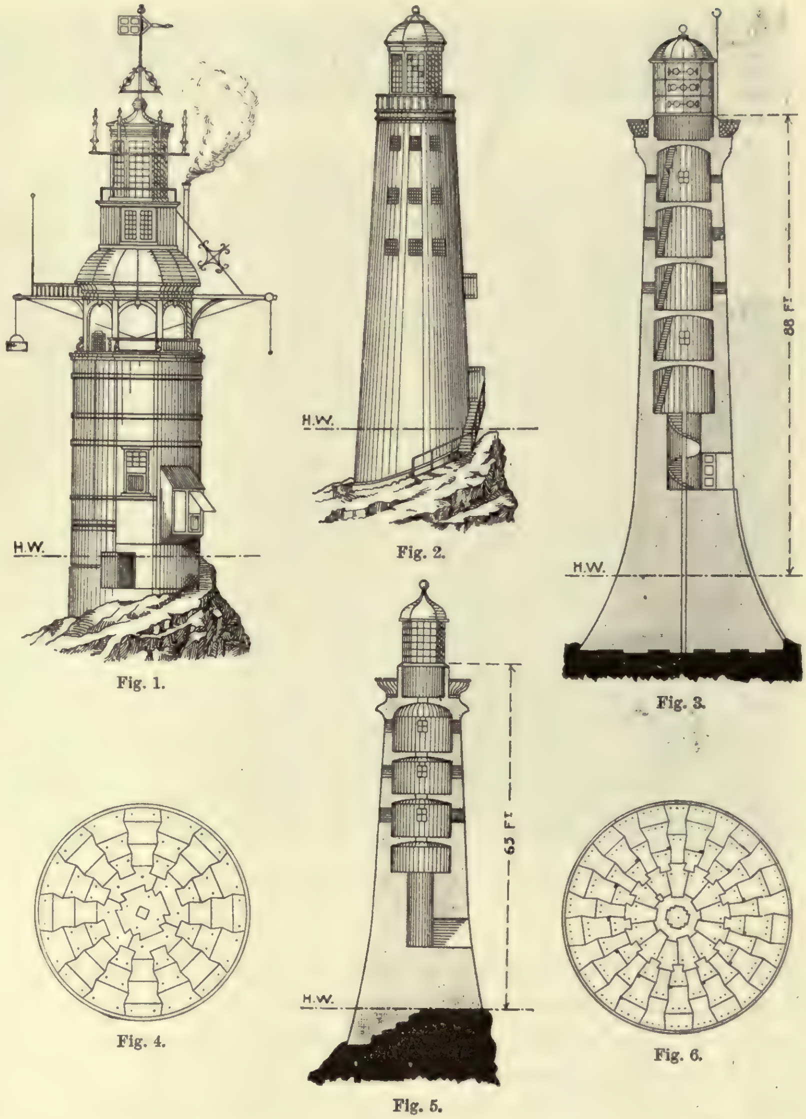


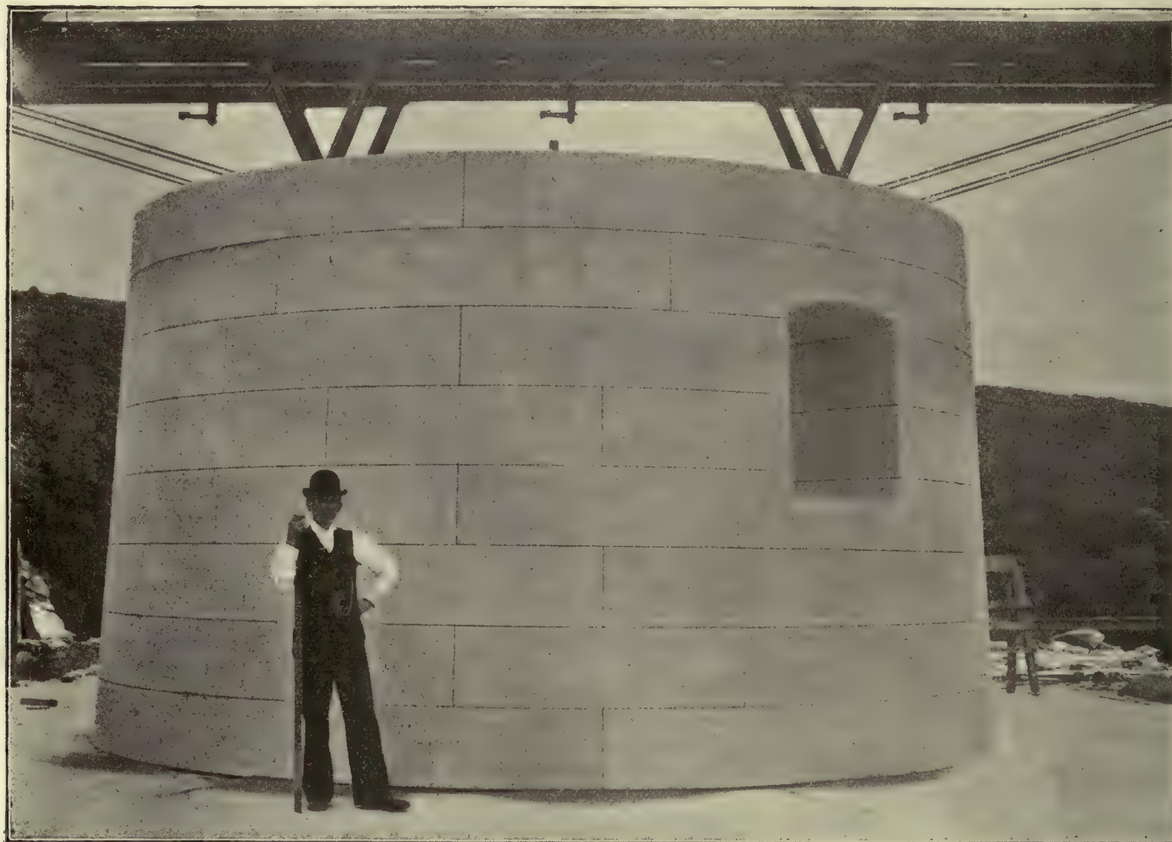
Fig. 1.—EDDYSTONE LIGHTHOUSE (Winstanley, 1698). Fig. 2.—RUDYERD'S EDDYSTONE LIGHTHOUSE (1704). Fig. 3.—EDDYSTONE LIGHTHOUSE (Smeaton, 1759). Fig. 4.—DOVETAILED JOINTS IN SMEATON'S EDDYSTONE LIGHTHOUSE. Fig. 5.—BELL ROCK LIGHTHOUSE (R. Stevenson, 1806). Fig. 6.—DOVETAILED JOINTS IN BELL ROCK LIGHTHOUSE.

Rudyerd's Eddystone Lighthouse.

Among the good points of this design were its circular form, presenting a smooth surface devoid of ornamental and other projections, its securely fixed base, and the employment of stone, so that the effect of weight might supplement the security afforded by mechanical attachment.

Smeaton's Eddystone Lighthouse.

When called upon to build a third tower on the Eddystone Rocks, Smeaton adopted granite as the material of construction, and shaped the stones, whose average weight was one ton each, so as to form dovetailed joints, as shown in Fig. 4. He



SEVERAL COURSES OF A LIGHTHOUSE FITTED TOGETHER AT THE QUARRY TO MAKE CERTAIN THAT THE STONES FIT ACCURATELY.

built the tower solid in the lower part, made it of circular form above with a curved profile, and added an overhanging curved cornice to throw back the crests of waves. (See Fig. 3.) Although Smeaton's tower was not free from defects, and may not have been altogether desirable for so exposed a situation, the general idea was correct, and virtually served as a model for the many larger and better lighthouses built during succeeding years. As an example, let us turn to the Bell Rock

Bell Rock Lighthouse.

Lighthouse, built in 1806 by R. Stevenson. Figs. 5 and 6 show that Smeaton's general profile and system of dovetailing have been followed, although the latter structure embodies undoubted improvements. One of these is the height of 100 feet as compared with 68 feet, thus raising the lantern above the highest breaking and reflected storm waves; another is the greater thickness of the walls, obviating the vibration from which Smeaton's tower suffered; and a third is the adoption of lintel stones for the floors, so shaped as to dovetail into the outer walls, as represented in Fig. 7. The latter arrangement is much superior to that in the former Eddystone Lighthouse, where the floors were genuine arches exerting thrust against the outer walls. To counteract this force chains were embedded in the masonry (see Fig. 8), but the result could not possibly be so satisfactory as the form of construction adopted by Stevenson. Owing to the great mass of solid material near the base of the Bell Rock tower, the centre of gravity of that structure is low, a circumstance giving stability against failure by overturning. The same feature is

Fig. 7.

Fig. 8.

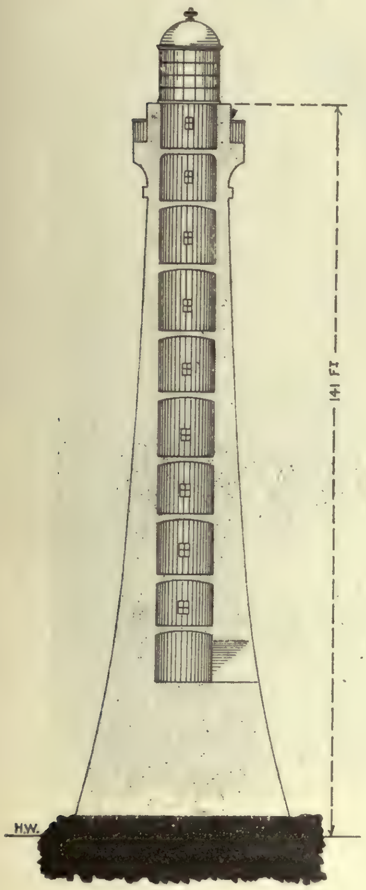


Fig. 9.

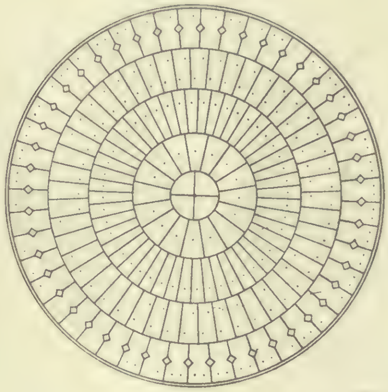


Fig. 10.

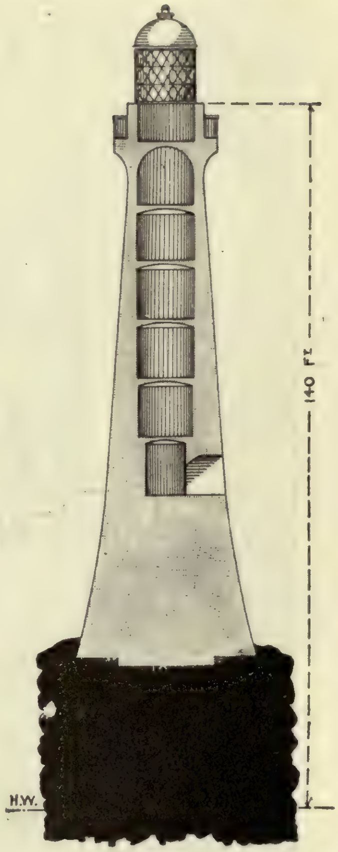


Fig. 11.

Fig. 11.—SECTION OF DHU HEARTACH LIGHTHOUSE.

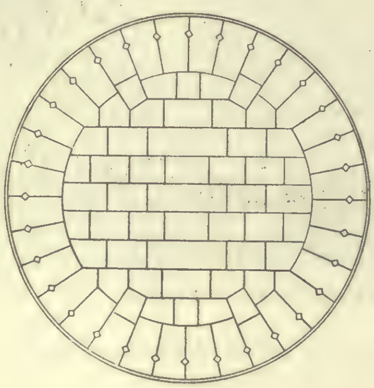


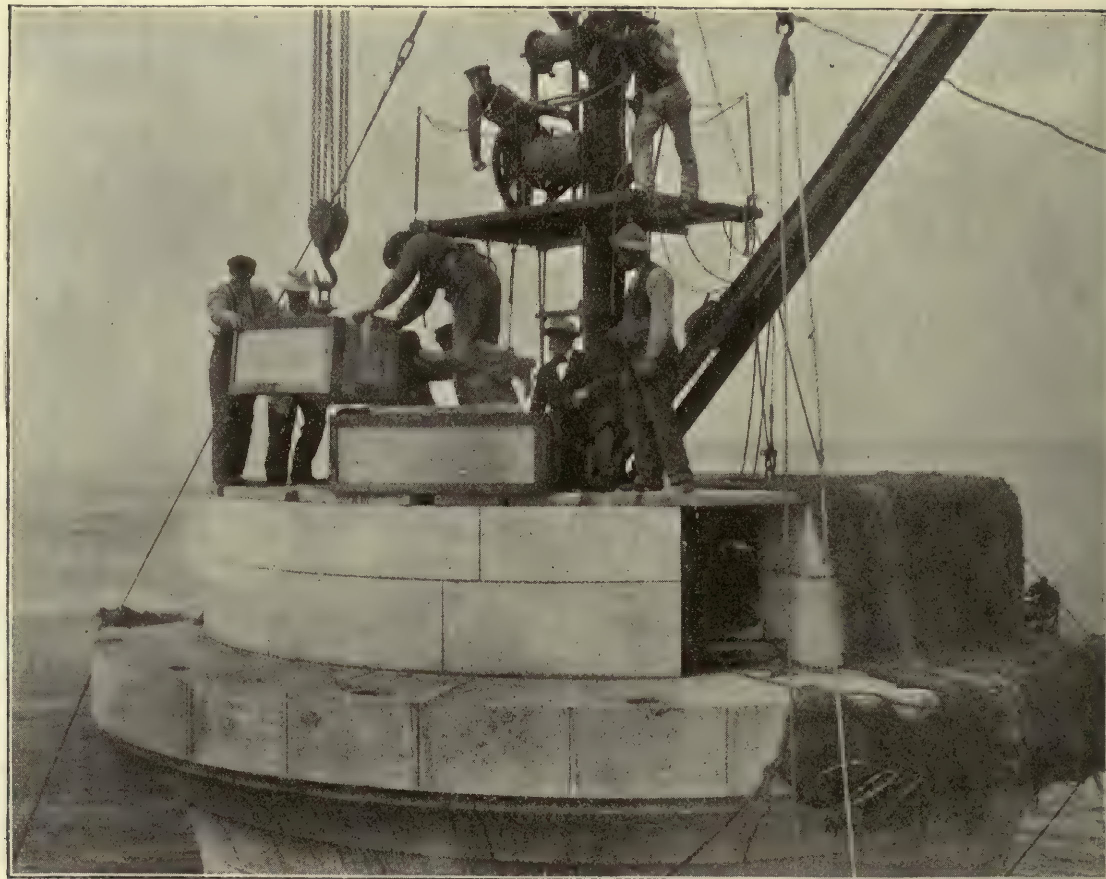
Fig. 12.

Fig. 7.—LINTEL STONES OF FLOORS OF BELL ROCK LIGHTHOUSE. Fig. 8.—ARCHED FLOORS IN SMEATON'S EDDYSTONE LIGHTHOUSE, WITH CHAINS EMBEDDED IN WALLS TO TAKE THE OUTWARD THRUST. Fig. 9.—SECTION OF SKERRYVORE LIGHTHOUSE (A. Stevenson, 1843). Fig. 10.—JOINTING OF MASONRY IN SKERRYVORE LIGHTHOUSE. Fig. 12.—JOINTING OF MASONRY IN DHU HEARTACH LIGHTHOUSE.

evident in Smeaton's tower, but not to an equal extent.

Attention may here be drawn to the fact that a masonry lighthouse *requires no fixing to the rock on which it is built*, because friction between the materials is quite sufficient to guard against any lateral displacement. It is very important, however, that the bottom of the tower should rest upon horizontal surfaces, either cut in the form of steps, as in Fig. 5; toothed, as in Fig. 3; or flat, as in Fig. 9. The object is to bring the weight of the structure upon the rock in a truly vertical direction, and to prevent the existence of any outward thrust. During the work of construction it is necessary to connect the stones to each other and to the rock in order to obviate the risk of any of them being washed away before enough weight has been superimposed to give security.

In stormy seas this risk is always present, and during the building of the Bell Rock



AT WORK ON THE TOP OF FASTNET ROCK LIGHTHOUSE. LOWERING A STONE INTO PLACE.
(*Photo, Chancellor.*)
Observe the protective casings of the stones, and the dovetailed joints.

tower massive blocks of stone weighing two tons were repeatedly torn out and swept into deep water, despite dovetailed joints and Portland cement mortar. The victories of modern engineering over the relentless forces of the ocean are aptly illustrated by the Skerryvore Lighthouse, built in 1838–43 by Alan Stevenson, and situated on a storm-swept reef in the open Atlantic, twelve miles from the island of Tiree, on the west coast of Scotland. Rising to an elevation of 141 feet above high-water level, this tower is a magnificent example of construction, its main features being shown in Figs. 9 and 10. To afford shelter for the workmen it was necessary to build a temporary barrack, which was so injured by the sea in 1838 that another one had to be constructed in a more sheltered position.

Skerryvore Lighthouse.

A structure of similar character is the Dhu Heartach Lighthouse (Figs. 11 and 12), built in 1867–73 from the designs of D. and T. Stevenson, on a lonely rock fourteen miles from the island of Mull. The workmen engaged in the construction of this tower were lodged in an iron drum, something like a huge circular tank, standing at a safe distance above the sea on a framework of wrought iron. Although the Dhu Heartach rock is about 35 feet above high-water level, the magnitude and force of the waves were such that during a summer gale several large stones, weighing two tons each,

Dhu Heartach Lighthouse.

THE STONE IN PLACE. (*Photo, Chancellor.*)

were carried away bodily from the lower courses at the height of 37 feet above high-water level.

Wolf Rock Lighthouse.

The Wolf Rock tower in the open sea between Lizard Point and the Scilly Isles was commenced from the designs of James Walker in 1862 (Fig. 14). Although the base is some feet below high-water level, the engineers were able to construct good landing-places, where materials could be delivered as opportunities arose, and used as required. The difficulties and dangers attending the execution of engineering works on storm-beaten reefs may be realized when we state that in the vicinity of the Wolf Rock waves have been observed of a height of 32 feet above the level of the sea, or 64 feet from crest to trough. As for landing and embarking men in rough weather, the only resource of the engineers, on many occasions when the sea suddenly got up, was "the rough-and-ready mode of being dragged through the surf and hauled into the boat like drowned rats." The lower part of the Wolf Rock tower was built in steps, which are undesirable because they cause shocks and vibrations which tend to disturb the masonry rather than to increase its stability. For the same reason the vertical base of the new Eddystone Lighthouse (Fig. 15) was much criticised at the time of its construction in 1878–82. Experience has proved, however, that this feature, introduced by the engineer, Sir J. N. Douglass, has had the effect of

New Eddystone Lighthouse.

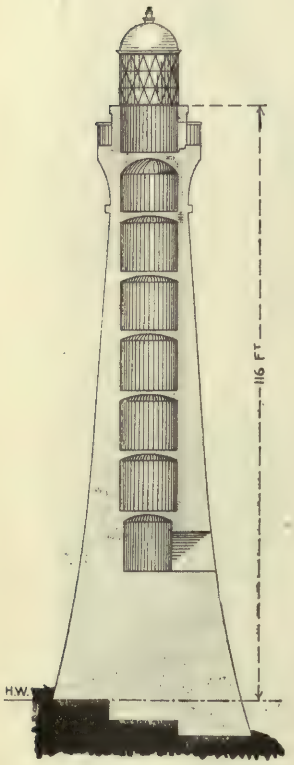


Fig. 13.

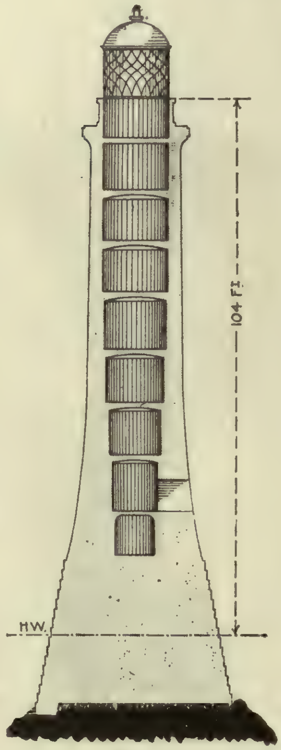


Fig. 14.

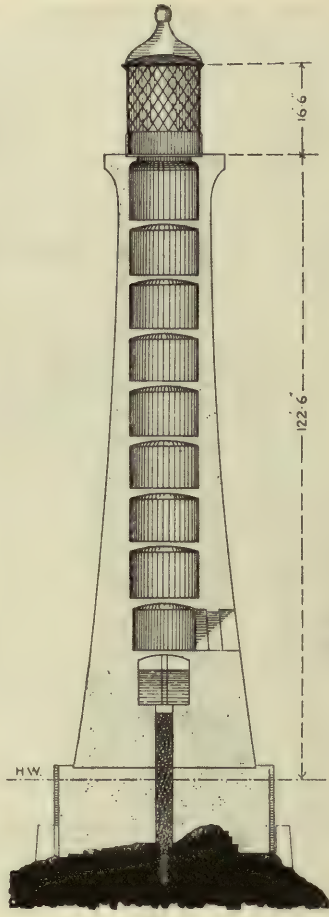


Fig. 15.

Fig. 13.—SECTION OF THE CHICKEN ROCK LIGHTHOUSE, CALF OF MAN (D. and T. Stevenson, 1874). Fig. 14.—SECTION OF WOLF ROCK LIGHTHOUSE, OFF LIZARD POINT (Walker, 1862). Fig. 15.—NEW EDDYSTONE LIGHTHOUSE (Douglass, 1883).

breaking the shock of waves to such an extent that spray alone ascends to the lantern gallery, 122 feet 6 inches above high-water level. Smeaton's tower was only about 60 feet high to the cornice, against which ascending waves broke and fell in heavy spray on the lantern. So violent were the shocks in severe weather that the stones of the cornice were lifted from their beds, while the vibration of the tower itself caused much anxiety. Moreover, the foundations were found to be partly undermined, and taking all things into account, the Corporation of Trinity House had no alternative but to decide on the construction of a new lighthouse. The site chosen was about forty yards away from Smeaton's famous structure, the upper portion of which now stands on Plymouth Hoe, and still serves a useful purpose to mariners as the Trinity sea-mark.

While less familiar to the general public than records of successive structures on the Eddystone, the story of the Bishop Rock Lighthouses is even more thrilling, and presents a vivid picture of the determination and undaunted courage displayed by British engineers in battling with the elements in their wildest mood.

Lying seven miles to the south-west of the

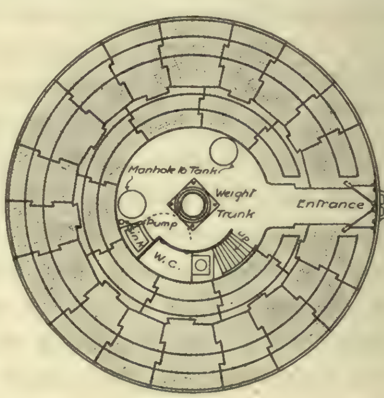
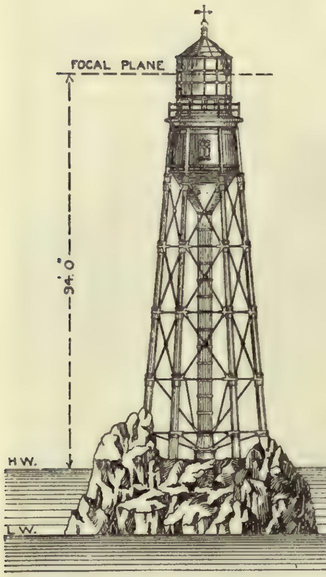


Fig. 16.—JOINTS IN MASONRY OF NEW EDDYSTONE LIGHTHOUSE.

The Story of the Bishop Rock Lighthouses.

Scilly Islands, the Bishop Rock was for centuries a perilous obstacle, scarcely discernible above the face of the sea, and dreaded by mariners of all nations. The rock is of a conical form, somewhat like that of a bishop's mitre, surrounded by deep water, and exposed to the full swell of the Atlantic, with a "fetch" of four thousand miles. Up to the year 1790 the rock-bound coast of the Scilly Islands was lighted by nothing better than an open coal fire at the top of a tower on the island of St. Agnes, several miles within the dangerous outer reef of water-washed rocks. The fatal disaster which befell Sir Cloudesley Shovel in 1707 when returning from Toulon with his fleet may have suggested anew the necessity for more efficient danger signals, but, owing to the slow development of lighthouse design, nothing more was done until 1790, when the Corporation of Trinity House installed in St. Agnes a revolving oil light, with "catoptric" or reflecting mirrors —the first of its kind on the coast-line of the United Kingdom. Even this light was not an efficient warning for ships beyond the outer reef, and in 1846 the Trinity House authorities at last decided to erect on the Bishop Rock a lighthouse with a fixed light of 6,500 candle power, and a range of about 17 miles. At low-water level the rock is only 153 feet long by 52 feet wide, and descends almost sheer to a depth of from 120 feet to 150 feet. Fig. 17 is a sketch showing approximately the form of the Bishop Rock, itself a natural tower of very hard granite. From this sketch it will be realized why, in 1845, it was thought that the width of the rock was inadequate to provide a safe resting-place for the base of a masonry tower exposed

Fig. 17.—APPROXIMATE FORM OF BISHOP ROCK. (THE INSET SHOWS ROCK WITH LIGHTHOUSE BUILT.)



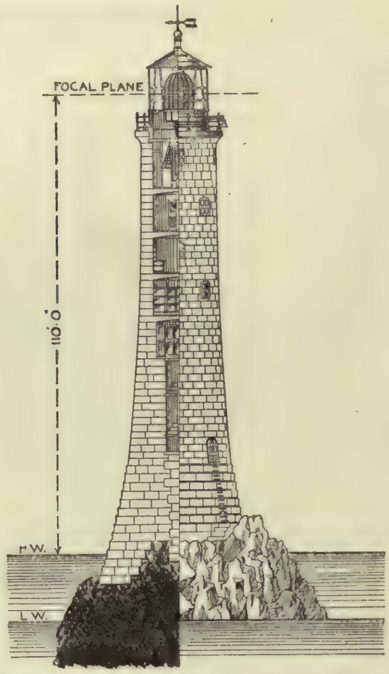


Fig. 18.—BISHOP ROCK IRON LIGHTHOUSE (Douglass, 1847).
Fig. 19.—BISHOP ROCK LIGHTHOUSE (Douglass, 1858).

to shocks of exceptional severity from waves which sometimes rise fifty feet above the summit of the rock. Hence it was thought best to build the iron lighthouse illustrated in Fig. 18.

The Iron Lighthouse of 1847.

Work was commenced in 1847, under the direction of Mr. N. Douglass, then the superintending engineer to Trinity House. The cast-iron columns, strengthened by wrought-iron cores and bracing, were sunk deep and keyed into the solid rock, the general idea of the design being to offer the least possible resistance to the onward sweep of the waves, whose extreme height would be well below the living rooms situated under the lantern, and the central column was made hollow, so that it might afford means of access to the upper part of the lighthouse.

The difficulties attending the erection of this structure were many and great. On one occasion an iron column weighing three tons was landed, but as the weather proved too severe for its immediate erection, one end was hauled and pushed into a safe sconce on a rocky ledge, where it was secured by a heavy chain attached to eyebolts let into the solid granite, while the other end was lashed to the main frame of the lighthouse tower. Three days later, when the sea had moderated, Mr. Douglass was able to approach the rock in a boat, and saw that the lower end of the column had been torn away and "tossed up twenty feet on to the top of the rock," where it was "swaying about horizontally like a piece of timber, being held only by the lashings at its upper end." On landing at the rock some days later the engineer found, among other evidences of the tremendous power exerted by the waves, that a blacksmith's anvil weighing $1\frac{1}{2}$ cwt. had actually been washed out from a hole 3 feet 6 inches deep and 2 feet in diameter, where it had been deposited for safety!

At last, after a battle with the sea lasting for four seasons, the tower was finished ready for the installation of the lantern and lighting apparatus. The structure was left in this condition in the autumn of 1849, and every one thought it would resist safely the winds and waves of the coming winter. This confidence was rudely destroyed during the month of February 1850. One night a great storm arose, and when morning dawned the rock was seen to be bare, nothing remaining of the tower but some short fragments of the main columns.

Still undaunted, the Corporation of Trinity House once more decided to build a lighthouse on the same site, and this time they determined upon the construction of a granite tower with

the height of 110 feet to the focal plane of the lantern (Fig. 19). In 1851 the work was commenced under the direction of Mr. N. Douglass, and in order to get the maximum possible diameter for the base, the lowest stone was laid at the depth of 17 feet below high-water level. An anecdote related by Mr. M. Beazeley concerning the foundation

The Granite Tower of 1851.

Fig. 20.—THE BISHOP ROCK LIGHTHOUSE IN A STORM.

(Drawn from a diagram by Mr. W. T. Douglass, M.Inst.C.E., and published in the "Proceedings of the Institution of Civil Engineers.")

stone of the "Bishop" illustrates the determination and pertinacity exhibited by Mr. Douglass. "The difficulty of getting the stone in," we are told, "was so great that the rest of the work had to proceed as best it could, and the stone had to be left out to wait a favourable opportunity."

Nearly three years elapsed before the stone could be laid, and at last the officials, who came down at intervals to inspect the work, began to lose patience. One of them said to Mr. Douglass, "I do not suppose you ever expect to live to get that stone in." Mr. Douglass was then by no means a young man, but retorted promptly, "I do; and remember that I have a father still alive." The stone was set near the end of 1852, and in 1858 the lighthouse was completely finished and brought into service. All stone for the construction of the tower had to be brought in barges from the workyard at St. Mary's and landed by manual labour—a tedious and hazardous method in a place where the calmness of the sea is a purely relative term.

Difficulty of Laying the First Stone.

Before many years had passed the Trinity House authorities had their attention drawn once more to the extreme violence of Atlantic seas in the vicinity of the Bishop Rock. Mr. W. T. Douglass tells us that the 5-cwt. fog-bell fixed on the lantern gallery of the light-

house, 100 feet above high water, was torn from its bracket during a severe storm and washed away, together with the flagstaff and ladder lashed to the gallery. A fragment of the bell was afterwards found in a cleft of the rock, and may be seen to-day at Trinity House. It seems almost incredible that water should rise to the appalling height of 100 feet in volume sufficient to sweep away huge masses of metal. That they did so is beyond all doubt. Sir James Douglass, who for two years worked with his father in the construction of the granite tower, stated in 1892 that in heavy seas "the primary wave flowed freely over the rock at a height of about 50 feet above its summit. There was very little break in the wave, except on the tower itself; and there a rather lighter wave rose and reached the cavetto of the lantern gallery, where was produced a third and still lighter wave of heavy spray, which struck the lantern, and, rising far above it, drove a long way to leeward, sometimes nearly a third of a mile."

Extraordinary Violence of Waves.

Fig. 20 is a sketch prepared from a diagram by Mr. W. T. Douglass, and gives a striking idea of the wild seas raging about the Bishop Rock, whose sugar-loaf formation doubtless aggravates the height of the waves in that stormy outpost.

While hurricanes were in progress, the tower of 1851 vibrated so much that objects were shaken from shelves in the living rooms, prisms of the lighting apparatus were fractured, and, finally, some blocks of granite were split by the excessive strain. These alarming occurrences led in 1874 to the application of heavy iron bolts to the interior surface of the walls; but despite this reinforcement further evidences of damage appeared in 1881, among them being the breaking away of pieces of granite weighing half a hundredweight each from the face of the outer blocks. Consequently, for the third time, the Trinity House were called upon to legislate for the Bishop Rock Lighthouse.

The Tower badly damaged.

Acting on the advice of Sir James Douglass, they determined to case the tower with masonry dovetailed horizontally and vertically from foundation to service-room level, and to continue the tower upward for four additional stories, with a new lantern whose focal plane would be 146 feet above high water, and showing a light having a range of about 20 miles. The outline of the improved tower, constructed under the superintendence of Mr. W. T. Douglass, is given in Fig. 21. It was designed to provide for the additional height of 36 feet, and to utilize to the utmost the width of foundation afforded by the rock.

An External Casing required.

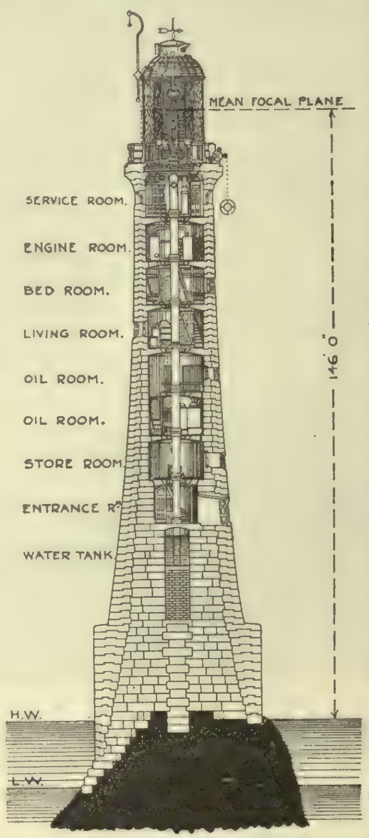


Fig. 21.—BISHOP ROCK LIGHTHOUSE: IMPROVED TOWER (Douglass, 1887).

The granite blocks forming the casing and new stories ranged in weight from 2 tons to 3¼ tons. They were carefully dressed and erected temporarily in the workyard at St. Mary's.

To provide for the conveyance of material from that island to the rock a small twin-screw steamer was bought. This vessel, origin-

ally built for the construction of the Great and Little Basses Lighthouses in Ceylon, had

Landing the Stones.

been fitted specially for the reception of stone blocks, stowed on elm rollers in the hold. The inside of the steamer is partly shown in Fig. 22, which illustrates the ingenious and elaborate arrangements made for landing materials. At the south side of the rock—where the water is very deep and ample space existed for manœuvring—three moorings were laid down, and three strong iron mooring stanchions were fixed on the rock. (See Fig. 23.)

When the steamer arrived with her cargo she was moored by stout hawsers; and the stones were then raised one by one from the hold, hauled

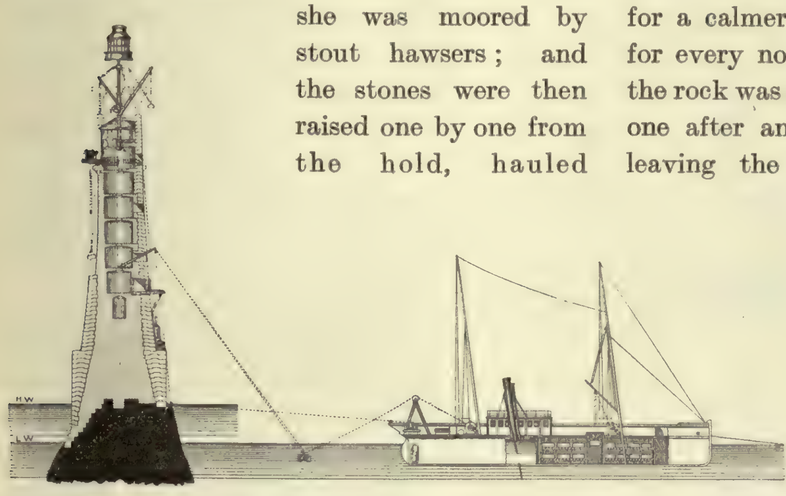


Fig. 22.—CONSTRUCTION OF THE IMPROVED TOWER OF BISHOP ROCK LIGHTHOUSE. DIAGRAM ILLUSTRATING METHOD OF LAYING STONES.

through the water, and finally hoisted to the required position on the tower by aid of the tackle represented in Fig. 22.

Difficulties encountered.

The process may seem from this brief description to have been very simple and easy, but those who know anything about the rolling swell of the Atlantic will be quite prepared for the statement that considerable trouble was experienced from time to time. Very often the blocks of granite, on emerging from the water, were struck by waves and set swinging from side to side, the movement being augmented by the heavy rolling of the little ship. The only thing then to be done was to dip the stone once more, and to wait

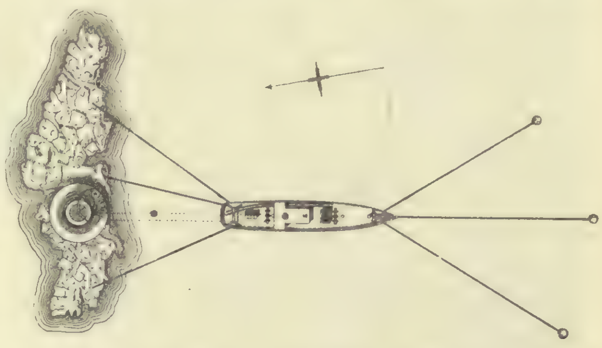


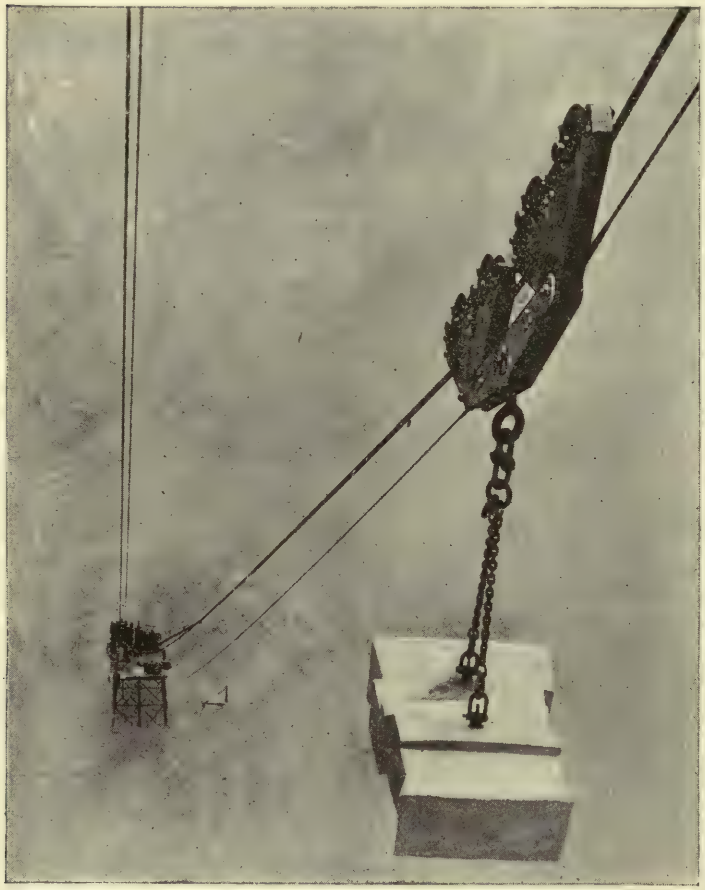
Fig. 23.—DIAGRAM SHOWING HOW BOAT WAS MOORED AND STONES WERE CONVEYED TO BISHOP ROCK LIGHTHOUSE.

for a calmer interval. But this was not all, for every now and then the backwash from the rock was strong enough to snap the hawsers one after another, like so much packthread, leaving the vessel attached to the outer moorings, but in danger of wreck amid the leaping waves and a tide running at the pace of from four and a half miles to five miles an hour.

Even when things were going as well as could be expected, the lurching of the steamer often caused the blocks to rise and fall several feet. To guard against injury, heavy mats were placed to receive the stones on the landing-place. Fortunately, no serious mishap occurred beyond the loss of one stone, which was jerked off the deck truck on which it lay, over the bulwarks, and into the water, as the result of a heavy sea striking the vessel abeam.

Instead of the rough-and-ready methods of landing and embarking men adopted in the building of former lighthouses, the working party were passed to and from the landing-boat by means of a rope connected with a winch fixed on the gallery of the old

Fixing the Stones.



STONE DESCENDING BY CABLEWAY FROM BEACHY HEAD TO THE SITE OF THE NEW LIGHTHOUSE.

(*Photo, Messrs. Bullivants, Limited.*)

tower. Thus the boat was enabled to lie at a safe distance away from the worst of the broken water and without risk of being stove in. The first operations were to dress back the face of the rock, and to cut dovetails for bonding the new masonry. This work was tedious, and could only be performed at favourable times. When at last the dovetailed casing of the old tower had been carried above mean-tide level, a dozen men were stationed permanently in the lighthouse for the purpose of seizing every opportunity of proceeding with the preparation of the outer surface for the new casing, when the weather was too rough for landing the whole of the working gang. Between low-water level and half-tide the work of dressing back the old masonry was no child's play, for at quite unexpected moments a huge wave would come rolling in, completely deluging the men. Therefore a life-line for each man was provided, all the lines being secured to a chain encircling the tower.

Safety Nets.

After the first year the task of battling with the sea became less arduous, thus permitting more frequent landings and longer hours of work. As the masonry rose above the vertical base, platforms for the masons were fixed around the tower, with nets beneath drawn lightly to the outer wall. This enabled the men to work with some feeling of security above the wild commotion at the foot of the rock. To facilitate the work of hoisting and setting the stones, a rotatory crane was fixed on the lantern gallery, but this appliance was superseded by the central crane illustrated in Fig. 22, consisting of a hollow wrought-iron mast 40 feet high, with two jibs for hoisting and setting; while above the top mast was fixed a Trinity House lantern provided with a powerful double flashlight. The landing and erection of the heavy mast was a work of extreme difficulty, but when once in place the crane proved of great assistance. In order to expedite the handling of stones landed on the top of the vertical base, a steam boiler and winch were secured to the platform in the position indicated by Fig. 22, and protected by masonry breakwaters.

As final illustrations of the almost inconceivable violence of the seas breaking upon the Bishop Rock, we may mention the follow-

PLACING THE LAST STONE OF THE BEACHY HEAD LIGHTHOUSE.

(Photo, Messrs. Bullivants, Limited.)

ing statements by Mr. W. T. Douglass. He says that during a severe north-west gale the heavy steam-winch, although protected by masonry and bolted to the landing-platform at the height of 22 feet above high water, was completely wrecked and washed away, nothing but the bolts and a portion of the bed-plate remaining. Again, a 12-inch iron block, fixed to the landing-jib at an elevation of 60 feet above high water, was struck by a heavy sea and swept away. Moreover, an iron cradle, suspended by massive chains beneath the lantern gallery at the height of 115 feet above high water, was torn from its fastenings and swallowed up by the sea. Mr. Douglass relates also the following incident as illustrating further the violence of the sea in exposed positions on the Scilly Islands. On the morning after a heavy storm from the north-west in the winter of 1886 he had occasion to visit Round Island, five miles away from the Bishop Rock. Large volumes of water had been driven over the summit of this island, 130 feet in height, and on the flat roof of the dwelling-house Mr. Douglass actually discovered a living limpet, as well as numerous small stones, carried by the force of the sea to an altitude of 143 feet above high water. Instances such as these are sufficient to give some idea of the tremendous forces which have to be encountered by those who undertake the building of lighthouses in positions like that occupied by the Bishop Rock.

What Ocean Waves have done.

ARRIVAL OF FIRST STONE OF THE BEACHY HEAD LIGHTHOUSE.

(Photo, Messrs. Bullivants, Limited.)

MAJESTY AND SPEED.

BY ALBERT G. HOOD,

Editor of "The Shipbuilder."

THE units of the world's fighting fleets may, for the purpose of this article, be divided into eight main classes—namely, Battleships, Cruisers, Scouts, Sloops, Gunboats, Torpedo Boats, Torpedo Boat Destroyers, and Submarines; and since there is frequently much confusion in the mind of the landsman as to the distinctive features of each, we shall, as we proceed, endeavour to indicate their respective characteristics.

The Battleship.

In a naval encounter the vessel upon which the belligerents would most rely is undoubtedly the battleship, the most heavily protected and armed type of warship designed. A well-known authority has recently summed up the requirements in the design of this class of vessel as follows: "A battleship should have such a form and dimensions as shall ensure good sea-going qualities, providing a steady gun platform in heavy weather, and ability to maintain a high speed at sea. Such a ship should also have a large radius of action—secured by ample fuel supply in association with economical fuel-burning and steam-using apparatus—and ample structural strength, not only under normal circumstances, but after damage in action; and must also carry a heavy gun armament well protected by armour, and be provided with armour for the protection of machinery and other 'vital' parts, as well as for the defence of buoyancy and stability."

Defensive Qualities.

When it is remembered that the battleship may have to withstand (1) heavy gun fire, (2) a torpedo or mine attack, or (3) possibly ramming, the magnitude of the task set to the designer in the provision of adequate defensive qualities will be appreciated. For protection against gun fire the ship must carry armour over as large a portion of her sides as possible, and protective decks. In addition to this hull protection, heavily armoured barbettes and casemates must be fitted to preserve from the enemy's fire the guns which will constitute the offensive power of the vessel. So important is this last consideration that, of the total weight set aside for protection, one-third is often utilized for the preservation of the armament. The coal fuel carried by the vessel above and below the protective deck must be so distributed as to further protect the vital parts of the ship against any shells which may pierce the hull; and the rudder, so important for manœuvring while the ship is in action, has to be fitted below the water-line to save it from injury by gun fire. The armour belt at the water-line must be specially efficient,

and indeed it is usually carried about five feet below water, resting upon the protective deck, as a shot piercing a rolling vessel at or slightly below the water-line might have serious results.

To provide against torpedoes and mines (which worked such terrible havoc during the Russo-Japanese war) an inner skin, forming a double bottom and double sides, and the most extensive water-tight subdivision possible, must be introduced in order to localize any inrush of water following a successful attack. Powerful searchlights must be carried to detect an enemy's torpedo craft approaching under the cover of darkness, and the smaller armament must be such as to disable a torpedo boat before she can approach near enough to discharge her deadly weapon. Torpedo net defence must also be employed; and, as a last resource, the explosives on board must be carried as far in from the sides and bottom of the ship as possible, so that the intervening bulkheads and platforms may prevent the shock of any external explosion from affecting the contents of the magazines.

The ram, it may be added, is no longer regarded as a weapon likely to be employed frequently in naval warfare, for the reason that its use against a modern battleship would be attended with almost as great a risk to the attacking as to the attacked vessel; hence no special provision, over and above that necessitated by gun and torpedo attack, is introduced against ramming.

Ordnance v. Armour.

The marvellous improvements in explosives and in the design and manufacture of guns have been, next to the introduction of steam propulsion, the most important factors in the development of warship design. These improvements, which have resulted in more effective gun fire being obtained with guns of smaller calibre and decreased weight, have followed each other in rapid succession, each in turn altering in a greater or less degree the conditions of naval warfare. Indeed, the evolution of the battleship has to a large extent represented a duel between the ordnance manufacturer and the armour-plate maker.

The first large armour-plated vessel constructed in this country was the *Warrior*, laid down in 1859. She was built of iron, and had a length of 380 feet. The armour, of wrought iron, 4½ inches thick, extended for a length of 218 feet and a depth of 22 feet on each side, the ends of the ship being unprotected. This 4½-inch armour was the thickest that could then be manufactured, and it was considered sufficient to withstand the attack of the guns at that time in use. For ten years after the *Warrior* was commenced, each successive class of large warships carried thicker armour than their predecessors, in order to meet the more powerful batteries which an enemy was likely to bring to bear on them. The *Devastation*, a special ship commenced in 1869, was so heavily protected that she had a very low freeboard, and it became apparent that in future designs either the area covered with armour would have to be reduced, or lighter armour employed. In 1874 compound or steel-faced armour was adopted, in 1889 nickel steel was introduced, and in 1894 "Harveyed" steel was used for the first time in British warships. The Krupp process is the latest word in armour manufacture, and still holds its own for the principal protection of war vessels.

The Magazines.

The ventilation of the magazines of warships has lately been made a special study. A cool and even temperature under all conditions and in all climates is ensured by means of refrigerating plant; and flooding arrangements, for use in case of fire, are fitted to all spaces where explosives are stored.

Other Features.

To minimize further the risk of fire breaking out when the ship is in action, the amount of woodwork is reduced to a minimum.

H.M.S. "DREADNOUGHT." (*Photo, S. Cribb.*)

The great Battleship which has revolutionized the views of all the Great Powers as to the requirements of naval warfare.

Wood decks are dispensed with and corticine substituted, and cabin bulkheads, fittings, store-rooms, etc., are now made of non-inflammable material, usually sheet-steel.

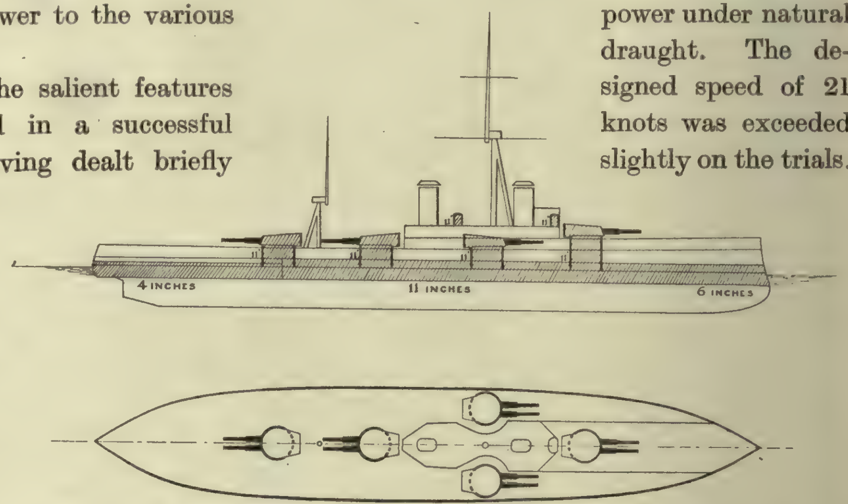
Automatic gun signals are fitted so as to prevent the occurrence of accidents through the cross-fire of the guns, and complete loud-speaking telephone communication is established from the conning tower to the various vital parts of the vessel.

Having now indicated the salient features which must be embodied in a successful battleship design, and having dealt briefly with the offensive and defensive qualities necessary, it will be of interest to describe somewhat in detail a modern battleship, and for this purpose we have selected the *Dreadnought,* the great ship whose advent revolutionized the views of all the great powers as to the requirements of naval warfare. The *Dreadnought* has been followed by the slightly larger *Superb, Téméraire,* and *Bellerophon* (18,600 tons displacement), the *St. Vincent, Collingwood,* and *Vanguard* (19,250 tons), and the *Neptune* (20,250 tons), for the British Navy; but, so far as the particulars of these vessels have been made public, they may be regarded as improved *Dreadnoughts.* The *Dreadnought* offered such a great advance in battleship design that the impression she made on the expert advisers of other naval powers may be clearly discerned in the designs of the new battleships *Delaware* and *North Dakota* for the United States Navy, the *Nassau* and *Rheinland* classes for Germany, the *Danton* and the five similar vessels for France, and the *Aki* and *Satsuma* for Japan.

New Battleships of the Great Powers.

H.M.S. "Dreadnought."

The *Dreadnought* is 490 feet long between perpendiculars, by 82 feet broad, and draws 26½ feet of water at a displacement of 17,900 tons. Her Parsons turbine engines drive four screws, take steam from Babcock and Wilcox water-tube boilers, and indicate 23,000 horse-power under natural draught. The designed speed of 21 knots was exceeded slightly on the trials.



DISTRIBUTION OF ARMAMENT AND ARMOUR ON H.M.S. "DREADNOUGHT."

The "Dreadnought's" Guns.

The armament consists of ten 12-inch guns, twenty-four Q.F. anti-torpedo boat-guns, and five submerged torpedo tubes. Thus the *Dreadnought* is an all-big-gun ship, or, in other words, she carries no 6-inch or other intermediate guns, such as were usually fitted in the earlier battleships. The advantages and drawbacks of the all-big-gun arrangement have been much discussed in naval circles, many contending that it is not wise to substitute heavy 12-inch weapons for the equivalent weight of intermediate guns; but the fact that more than one of the great naval powers in their latest ships have followed the *Dreadnought* lead is not without significance. In the arrangement of armament adopted, which is shown on this page, six of the big guns are mounted in pairs on the centre line of the ship, and the remaining

H.M.S. "KING EDWARD" IN DOCK FOR CLEANING. (Photo, S. Cribb.)

four are mounted in pairs on the broadside. Thus eight 12-inch guns—80 per cent. of the main armament—can be fired on either broadside, and four, or possibly six, 12-inch guns—or 60 per cent. of the main armament—can be fired simultaneously ahead or astern. In adopting this arrangement, her designer (Sir Philip Watts) had in view that, while broadside fire is held to be the most important in a battleship, all-round fire is also of great importance, since it lies in the power of an enemy to force an opponent, who is anxious to engage, to fight an end-on action. In view of the terrible potentialities of modern torpedo craft, and especially considering the chances of torpedo attack towards the end of an action, the numerous anti-torpedo-boat guns are separated as far as possible from each other, so that the whole of them could not be disabled by one or two heavy shells.

What a 12-inch Gun can do.

Some indication of the havoc likely to be wrought in any future naval battle by the great 12-inch guns of our latest battleships may be gathered from experiments carried out early in 1908 with a Hadfield 12-inch "Heclon" capped armour-piercing shell, fired with a velocity of 1,986 feet per second at a 12-inch Krupp-cemented plate. Not only did it perforate the plate, but it passed through three feet of oak backing, and after indenting two heavy steel plates in the butt the shell was recovered undamaged.

The "Dreadnought's" Armour.

The *Dreadnought's* main armour belt has a maximum thickness of 11 inches, tapering to 6 inches at the forward and 4 inches at the after extremity of the vessel; the redoubt armour varies in thickness from 11 inches to 8 inches; the turrets and fore conning tower are 11 inches thick, and the after conning tower is 8 inches thick. The protective deck varies from 1¾ inches to 2¾ inches in thickness. Special attention has been given to safeguarding the ship from destruction by under-water explosion. All the main transverse bulkheads below the main deck—which is 9 feet above the water-line—are without doors, and are unpierced except for the purpose of leading pipes or wires conveying power. The inconvenience in passing from one part of the ship to another caused by the absence of doors is partly overcome by the provision of lifts and other special arrangements to give access to the various compartments.

Speed of Battleships.

Coming to the question of speed, a battleship must be well-balanced—that is, efficient armour and armament must not be sacrificed in order to obtain high speed, for, after all, she is intended primarily to remain where the fight is thickest, and not to show a clean pair of heels. On the other hand, high speed and great fuel endurance give a better chance of obtaining a strategic advantage over an enemy, and better opportunity on going into action for choosing a range of fire that will suit the guns carried. These were the considerations which resulted in the decision to make the *Dreadnought* capable of steaming 21 knots, an unprecedented speed for a battleship.

Reasons for Fitting Turbine Machinery.

Turbine machinery, instead of piston engines, was adopted for the *Dreadnought* on account of the saving in weight and in the number of working parts; reduced liability to breakdown; diminished coal consumption at high powers, and hence extra boiler-room space; saving in engine-room complement; and increased protection, due to the engines being placed lower in the ship.

Cost of Warships.

The cost to the nation of the formidable fighting machine which the *Dreadnought* undoubtedly is, was about £1,813,000. With increased size and augmented offensive and defensive powers, the cost of war vessels of all

descriptions has, of course, advanced proportionately. Well within living memory, the cost of a first-class battleship did not exceed £500,000. It is therefore not surprising that there are at present critics who contend that, considering the necessary limits of expenditure and the requirements of a navy having such wide responsibilities as our own, we should not increase materially the size of the ships now being built, and that in ships of the *Dreadnought* class we have already gone too far. A disaster to one of these vessels, either in peace or in war, would be a great financial blow to any navy, and there would not be wanting people to tell us that we should not put "too many eggs in one basket." At present, however, Britain, like all the other great naval powers, is turning her attention to battleships and armoured cruisers of a size and cost never previously contemplated.

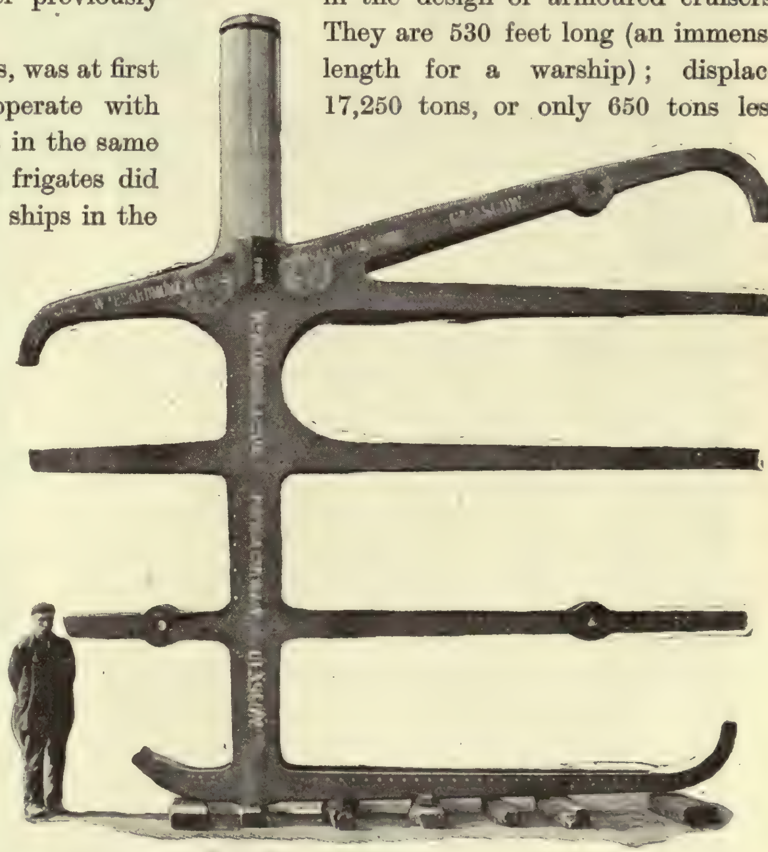
Protected Cruisers.

The cruiser, as its name implies, was at first intended to co-operate with armour-clad fleets in the same manner as sailing frigates did with fleets of sailing line-of-battle ships in the days when England's sea supremacy depended on her "wooden walls." The essential features of the cruiser were at first considered to be great speed, protection without the use of side armour, a powerful armament, and minimum size and cost. These conditions gave rise to the "protected cruiser"—that is, a vessel with the machinery and other vital parts covered with a thick armoured deck, minute watertight subdivision, and coal bunkers so arranged as to give the maximum side protection. It may be remarked that two feet of coal is equivalent in resisting power to one inch of iron, and consequently the disposition of the bunkers is of primary importance when the ship carries no side armour.

Armoured Cruisers.

With the building of the *Cressy* type of cruiser (1897), the "armoured cruiser" was really introduced into the British Navy, although a narrow armour belt had previously been adopted in the *Orlando* class. The quality of armour manufactured on the Krupp process had been so much improved by this time that it was found possible to protect the sides of cruisers for about half their length with a belt of 6-inch armour, $11\frac{1}{2}$ feet deep, and to close in the ends with bulkheads 5 inches thick.

The *Invincible*, *Inflexible*, and *Indomitable* (laid down in 1905) represent the latest word in the design of armoured cruisers. They are 530 feet long (an immense length for a warship); displace 17,250 tons, or only 650 tons less



THE RUDDER FRAME OF A BATTLESHIP.

(*Photo, Messrs. William Beardmore and Company.*)

H.M.S. "INDOMITABLE" AT FULL SPEED ON HER TRIAL TRIP. (*Photo, Russell and Sons.*)

than the battleship *Dreadnought;* and have a designed speed of 25 knots. The armament consists of eight 12-inch guns, sixteen 4-inch Q.F. anti-torpedo weapons, and three 18-inch submerged torpedo tubes; while their armour belt is 7 inches thick amidships, so that they well merit the title of "cruiser-battleship" sometimes applied to them.

Scouts.

Only a passing reference need be made here to the smaller British cruisers, intended mainly for the protection of our interests in distant parts of the world. In order to enable them to remain afloat for long periods without dry docking, cruisers built for this purpose are sheathed with wood and copper. Since the advent of powerful armoured cruisers, the building of large protected vessels has to a large extent ceased. It is, however, interesting to record that there has arisen a demand for small but very swift cruisers for scout duty. This requirement was met a few years ago by the British Admiralty ordering eight special scouts similar to the *Adventure.* These vessels displace about 3,000 tons, and, with their reciprocating or piston engines, attain a speed of 25 knots. Only light guns are carried, and two 14-inch Whitehead torpedo tubes. Still more recently, the United States completed the building of three somewhat larger vessels of the Scout class, named the *Birmingham, Chester,* and *Salem.* The first-named was fitted with piston engines, the second with Parsons turbines, and the third with Curtis turbines. The performances of both the turbine-driven vessels surpassed that of the *Birmingham,* the *Chester* attaining 26·5 knots on a four hours' trial, while the *Salem* steamed 25·95 knots. The *Boadicea* and the five cruisers ordered by the British Admiralty at the end of 1908 may also be termed scout-cruisers, as they will combine high speed with better sea-going qualities than those of the *Adventure* class.

Sloops and Gunboats.

Regarding sloops and gunboats, little need be said. In the sloops of the British Navy, usually of about 1,000 tons displacement, no attempt is made at protection, except in the arrangement of the coal bunkers. Like many second-class cruisers, they are frequently sheathed with wood and copper, as they are chiefly employed in foreign waters, and have often to remain afloat for long periods without dry-docking. They are mostly fitted as sailing vessels as well as having steam power.

Vessels spoken of as gunboats include numerous small ships intended in times of peace for patrolling rivers and round islands, protecting fisheries, and the other numerous duties allotted to the smaller warships. Those intended for river work sometimes draw very little water, to enable them to proceed up shallow waterways, and a few are propelled by stern-wheels.

Torpedo Craft.

After the battleships, the most interesting units of a fighting fleet to the man in the street are the torpedo craft, and no other type of warship has been more closely studied by experts. The torpedo boat, which dates back to about 1876, is armed only with torpedo tubes and very small guns, the essential feature being high speed. Intended solely as a weapon of offence, she is practically without any protection, if we exclude that afforded by her small size and high speed. A well-aimed shot from a battleship or cruiser would work disaster in a lightly constructed torpedo boat; but the swift and deadly nature of her attack, and the difficulty of meeting it in the ship attacked, make her a force to be carefully reckoned with. To meet the torpedo boat, torpedo-boat destroyers were brought into existence. Their larger size, heavier armament, higher speed, and greater fuel capacity enabled them to overtake the torpedo boats before they could launch their torpedoes

THE DECK OF THE "INDOMITABLE," SHOWING THE FOUR MIDSHIP 12-INCH GUNS. COALING AFTER THE RECORD RUN FROM CANADA TO ENGLAND.

(*Photo, S. Cribb.*)

at the great battleships and cruisers. It soon became apparent, however, that these additional powers enabled the destroyers to carry out more efficiently the duties of the torpedo boats, and they have rapidly superseded the latter. The building of torpedo boats has gradually diminished, the so-called torpedo boats recently added to the British Navy being really small destroyers.

The most important recent additions to the torpedo flotillas of the British Navy are the ocean-going destroyers of the *Tartar* class.

33-knot Destroyers.

These vessels are each about 270 feet long, and displace about 900 tons, and their armament consists of two 18-inch torpedo tubes and three 12-pounder Q.F. guns. For the great speed aimed at—33 knots—turbine machinery was fitted, driving three screws, and each vessel develops about 14,500 horse-power. All the five vessels so far completed have done remarkably well, and at least one proved herself capable of spurting for a mile at slightly over 37 knots.

The enormous energy within the lightly constructed hull of a destroyer—about 14,500 indicated horse-power in a 33-knot boat—

A Destroyer's Trials.

naturally requires the closest attention and presence of mind on the part of those charged with the ship's navigation and propulsion. On her trial trip she is called upon to race her hardest, for not only must she fulfil the stringent requirements as to speed of the British or other Government for which she is intended, but her builders, eager to enhance their reputation, want to see their boat surpass all others of the same class, and, if possible, earn a bonus for increased speed. On the day before such a test, the needful coal or oil is taken on board, the boilers are filled to their proper working level, and the steward for the occasion gets in his supply of solid and liquid refreshment for the trip. Fires are got away; and soon, thanks to the water-tube boilers, steam pressure shows in the gauges. All being in readiness below, the pilot, Government officials, and representatives of the builders come on board, and the vessel proceeds to the open sea in charge of a tug. The tug having been cast off, and the steam in the destroyer's boilers having risen to the required pressure, the valves are opened wide, and a flying start is made on the measured mile. In the stokehold and in the engine-room all is now one continual roar, and the whirl of rapidly moving machinery is quite sufficient to strike terror into the heart of the novice. It is, perhaps, fortunate that there is so much to do, and that no time is left for contemplating the possible results of a breakdown. In the meantime the ship, like a thing of life, is flying through the water, leaving behind her a wake of white foam churned up by her screw propellers; and in two minutes (or rather less) the end of the mile is reached. Now she is turning, and the whole vessel heels over as she swings round to race down the course again. In the engine-room and stokehold faces are getting blacker and blacker; and the smell of oil, the sweltering atmosphere, and the peculiar motion of the ship become unbearable to all save the veterans of previous trials. The strain on all is terrible, but there is grim determination in those begrimed faces; and while some of the "greenhorns" may give out, the older hands stick bravely to their posts. And so the trial proceeds, until at last the engine-room telegraph signals the welcome word "Stop!" With a feeling of relief we go on deck, and learn how the ship's funnels flared and became red hot, how all had to hang on to the rails when she came down the course in the teeth of the wind, and how she steamed (according to the deck hands) 34 knots and seven decimals. All are elated at the speed obtained, for has not our "catcher" (all destroyers are catchers in shipbuilding par-

lance) beaten the best record of her sister on trial last week by ·2 of a knot, and are we not for the moment "cock of the walk"?

The Submarine.

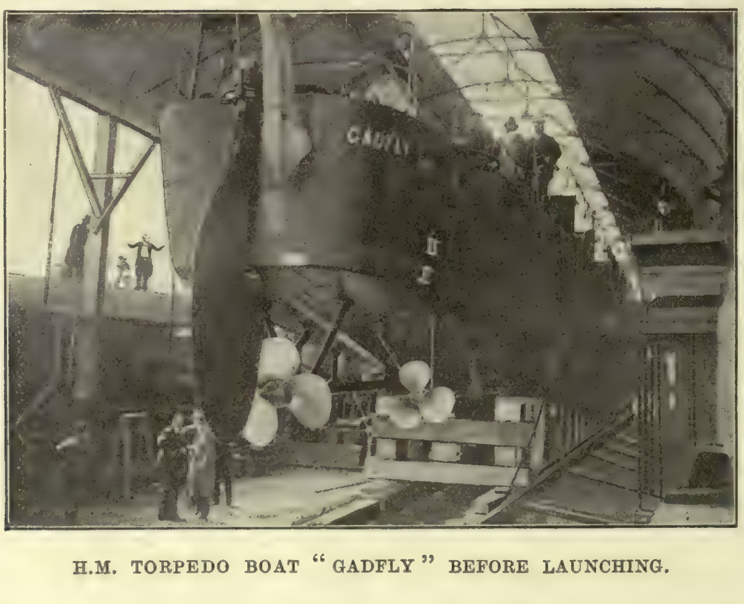
In naval warfare the submarine is expected to prove thoroughly efficient for the following purposes:—(1) For coastal defence, (2) to prevent bombardment of harbours and to render a blockade impossible, (3) to prevent the landing of troops, (4) in narrow waters to take the offensive on the enemy's shore and to torpedo their ironclads whenever they leave port, and (5) to render insecure all routes of navigation in European waters. Submarines have usually a cigar-shaped form. In many submarines electricity is the power employed, but in the later types internal-combustion engines have been adopted for propulsion while navigating on the surface, and also for recharging the accumulators which supply the propulsive power for navigation below the surface. In the later vessels the radius of action, both while submerged and on the surface, has been greatly increased; but compared with that of surface craft it is, of course, limited, hence the "parent" ship is a necessity for the sustained manœuvres of a submarine flotilla.

Offensive Power.

As regards offensive power, the submarine proper (unlike the larger submersible adopted in the French Navy) is armed only with torpedoes. It is interesting to note that the operation of firing a torpedo from a submarine is attended with greater accuracy than in the case of an ordinary torpedo boat or destroyer, as the latter is more subject to surface disturbances.

Future of the Submarine.

How far the submarine is destined to modify or displace other fighting vessels forms an interesting subject for speculation. The technical authorities of all the great naval powers are earnestly studying the numerous problems associated with submarine navigation and attack, and the secrecy observed in connection with their experiments unmistakably proves the importance attached to these new instruments of warfare.



H.M. TORPEDO BOAT "GADFLY" BEFORE LAUNCHING.

INTERIOR OF MESSRS. VICKERS SONS AND MAXIM'S ARMOUR-PLATE PLANING SHOP, SHOWING MACHINES PLANING PLATES TO SIZE REQUIRED.

THE ARMOUR OF A BATTLESHIP.

BY ALAN H. BURGOYNE.

IN designing a warship the naval constructor has to keep in view the three methods of attack to which his creation may be subjected. These are the ram, the torpedo (or mine), and the gun. Of these first two nothing need be said here, since they deal with attacks upon the submerged portion of a vessel's hull, where, with rare exceptions, no armour has yet been placed, and where, indeed, it is doubtful if armour would prove of any value. The best defence against the mine and torpedo, as also against the ram, is afforded by minute subdivision of the hull into water-tight compartments. For protection against gun-fire, the side of the ship is covered as much as possible by armour-plates, and there is a constant difficulty in meeting the dual desire to give the maximum thickness of plate and at the same time to cover the largest possible area of exposed surface.

The belief is often expressed that the belt and side armour are the only defences of a battleship. Armour is to be found in a dozen different positions within the body of the ship itself, and the main belt is backed up by the coal bunkers—coal being a most valuable defence against the entry of projectiles—and at its upper and lower edges is based upon thick curved steel decks forming a defensive carapace for the protection of the engines and other internal mechanism of a warship.

Early Armour.

INTERIOR OF MESSRS. VICKERS SONS AND MAXIM'S ARMOUR-PLATE ROLLING MILL, SHOWING AN ARMOUR PLATE BEING ROLLED.
The overhead travelling crane is able to lift 60 tons. The enormous 3 feet diameter rolls of the mill, driven by 3,000 horse-power, can reduce an ingot 36 inches thick to 6 inches in one heat.

The first large vessel provided with armour protection in this country was the battleship *Warrior*, launched in 1860. This ship was built of iron, and for 218 feet of her length of 380 feet she was protected by a 4½-inch wrought-iron belt having a depth of 22 feet from top to bottom. From the *Warrior* period until 1874 no change was made in the quality of the armour, though it was extended over a larger surface of side in later ships, and arranged so as to give protection to the ends and the rudder-head—omitted from the defence of the *Warrior*. When, as guns improved, the thickness of iron necessary to exclude the shells they fired could not be carried by the ships without detrimentally affecting their buoyancy, it became essential to discover a new mode of defence. This was found in what is known as "compound" armour. Compound armour consists of a steel plate artificially attached to a wrought-iron backing-plate of twice its thickness, the result being a plate with the hardness of steel on its face, by which projectiles are broken up, and the toughness of wrought iron at the back, which prevents cracking taking place. At this time all the armour was concentrated along the waterline, though we, in our ships, sacrificed the protection of the ends to the higher defence of the sides amidships. But the advent and rapid development of the quick-firing shell-gun rendered the large areas of unprotected sides an element of most serious danger.

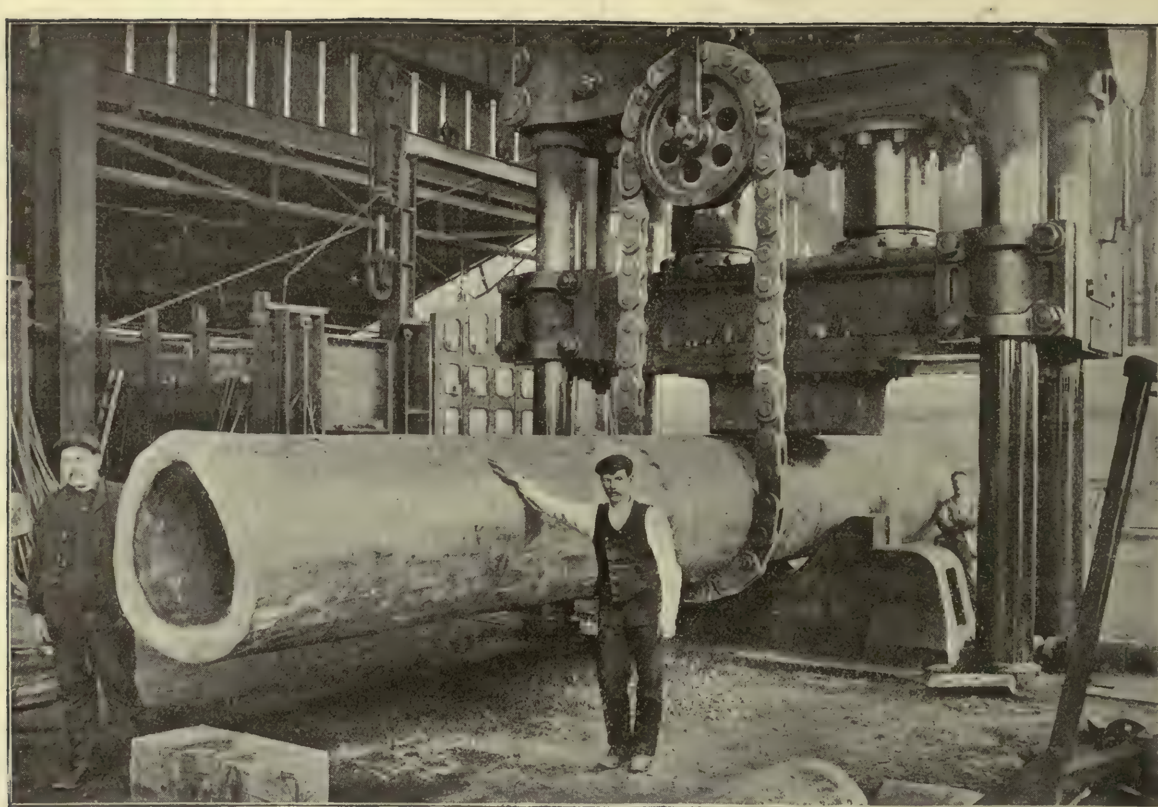
Harvey—

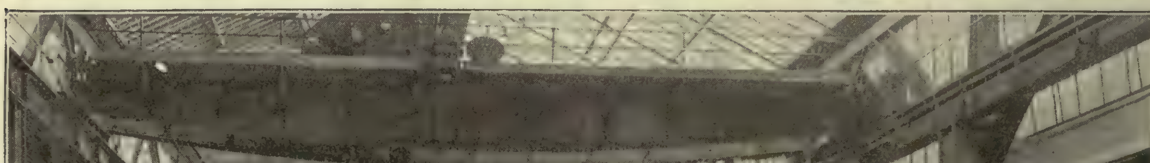
This involved a further advance in the manufacture of armour. Perhaps the most remarkable feature of the endless battle of armour *v.* gun is, that if at any time the former leads and baffles the gun, the energies of inventors speedily improve the weapon; whilst immediately afterwards the armour-plate manufacturers produce a plate able to withstand the new weapon; and so the fight goes on. The new material was what is known as the Harvey process armour. In this process all-steel plates are used. Animal charcoal is placed next the outer face (two plates being usually dealt with together, face to face), and the whole is then covered in with bricks and run into a gas furnace, where it remains for about three weeks, seven days being allowed for cooling. In this way the proportion of carbon on the face is increased, and the front is thus capable of being hardened. The plate is then bent to the required shape, and all necessary holes are made in its surface. It is then again heated, and the face douched with cold water, which makes it exceedingly hard. The object to be attained is a steel plate, without welds, having such a proportion of carbon in the surface that water cooling shall produce a very hard face.

And Krupp Processes.

The Harvey process of manufacturing armour was soon superseded by the Krupp method. The steel for this purpose contains small proportions of chromium, nickel, and manganese. All plates above 4 inches in thickness are cemented, and are termed Krupp cemented, or K.C. The smaller plates are termed K.N.C., or Krupp non-cemented. The cementing is carried out in a fashion similar to that described above.

Just a few words as to the manufacture of the steel itself. This is made from hematite pig-iron in rectangular furnaces heated by gas. In steel-making, quantities of 40 to 50 tons, or even up to 100 tons, are dealt with in each furnace charge. Pig-iron is placed on the bottom of the chamber, together with scrap steel to the extent of about 20 per cent. of the total weight, and the charge is then thoroughly melted. Iron ore, consisting chiefly of peroxide of iron, is then thrown into the molten mass. The oxygen in the ore combines with the silicon and carbon in the pig-iron; large quantities of gas are given off, causing a violent "boil" in the molten mass, and this brings every part of the metal under the oxidizing influence

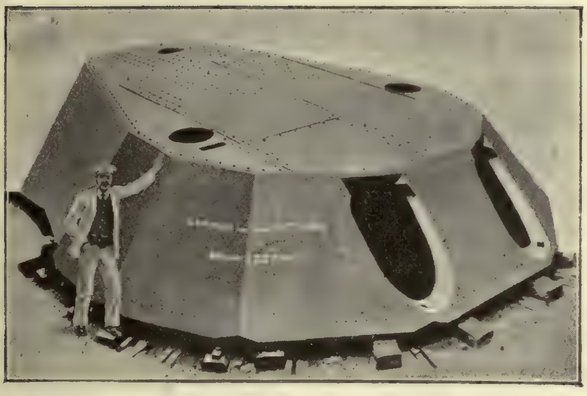




STEEL COMMUNICATION TUBE FOR BATTLESHIP'S CONNING TOWER BEING FORGED IN HYDRAULIC PRESS.

Length, 29 feet 1 inch; outside diameter, $39\frac{1}{2}$ inches; inside diameter, 28 inches; weight, 31 tons 5 cwt.

ASSEMBLING GUN BARBETTE SHIELDS AT MESSRS. VICKERS SONS AND MAXIM'S WORKS, SHEFFIELD.



A BARBETTE SHIELD FOR TWO 12-INCH GUNS.

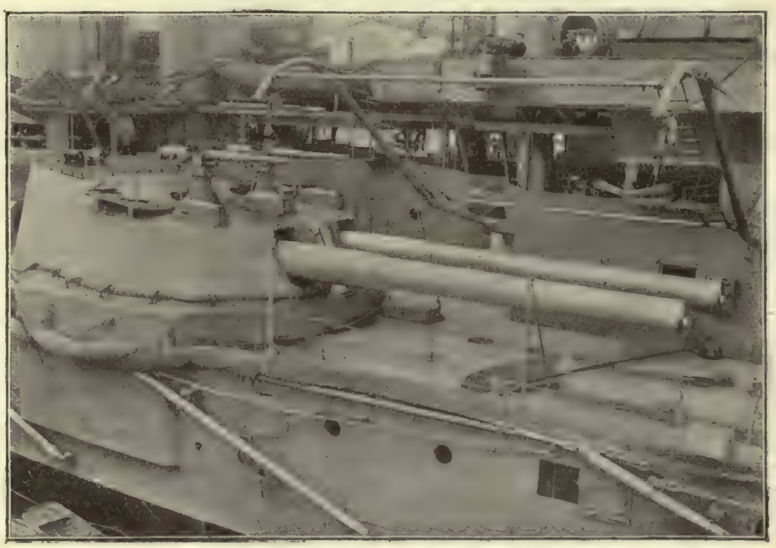
Note how the sides are sloped to diminish the force of a shell's impact.

of the ore. After all action has ceased, the metal is tapped through a hole in the side of the furnace into a large ladle holding 40 or 50 tons, and, while it is running out, ferro-manganese in a finely divided form is thrown into the ladle, where it melts and combines with the purified iron, its function being finally to remove all oxides and leave the residue in an almost pure metallic state. From the ladle the metal is tapped into rectangular cast-iron moulds, in which it cools to form blocks known as "ingots." These ingots are easily converted, by reheating and rolling, into any desired article.

Backing of Armour.

The belt armour of warships is based upon a "backing" and "supports." A massive system of framing is provided behind the armour, with a layer of picked teak, usually about 4 inches in thickness, to form a bed at the back of the plates. In all cases the skin or hull plating of a ship behind armour is arranged in two thicknesses. In addition to this wood, a solid steel framing is placed to withstand the blows upon the steel outer surface. Thus, in the *Majestic* class of battleship the 9-inch armour-belt has 15-inch plate-frames worked across it, 2 feet apart, with, in addition, horizontal stiffening girders. Barbettes, although well fitted by their shape to withstand blows, are supported inside the double thickness of plating by closely-spaced vertical girders. Behind armour, where men are likely to be employed in action, the inside of the framing is also covered with plating. When armour is struck, rivets are likely to break and their heads to fly off, so that this lining gives a necessary protection to the men inside.

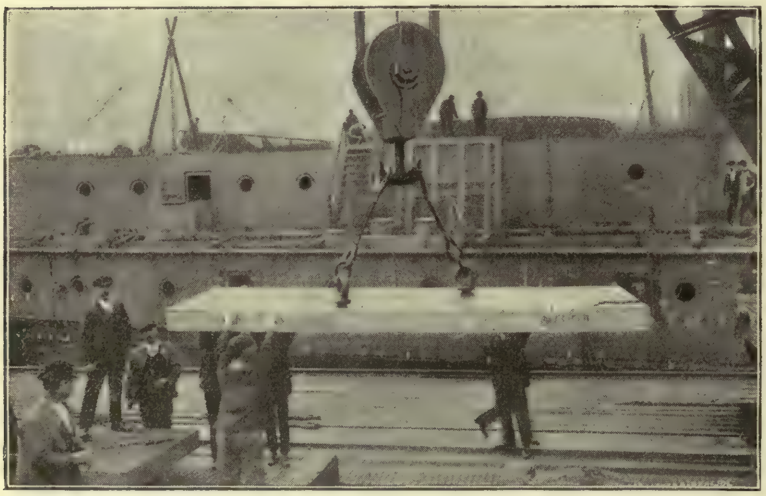
The method of fixing armour to its backing and the main framework of the ship is not generally known. With hard-faced armour, such as is universally used to-day, the surface must not be pierced for bolts, since it would be liable, if struck in action, to crack badly from hole to hole. Armour bolts are now screwed into holes driven into the back of the plate, about one bolt being allowed to every 7 square feet. In order to diminish the liability of bolts to break under the impact of projectiles, the shank, or end farthest away from the screw-thread fitting into the



(*Photo, S. Cribb.*) A SIDE BARBETTE ON H.M.S. "DREADNOUGHT."

plate, is made of lesser diameter. The bolt, if weakened, would stretch or break at this weakest part rather than at the thread. Finally, the nut securing the inner end of the bolt to the ship is fitted with a rubber washer in order to absorb shock.

Above the main belt is usually placed a second armour-strake of thinner plates. Similarly, the thickness of the armour forward and aft of the main gun positions is not as a rule nearly so great as at the centre. The armour in the bows is carried higher than in the stern, as a protection against damage there that might lessen a ship's speed by the admission of water.



LIFTING AN ARMOUR-PLATE INTO POSITION. (*Photo, S. Cribb.*)
The great thickness of the plate may be gauged by the comparative size of the hands of the man in the foreground.

Supporting the belt, and next to it in importance for the defence of the hull of the ship, are the armoured decks. There are usually two of these, curved towards their centre section, and carried down on either side to meet the top and bottom of the main belt. The curve is provided for two reasons—first, that a shell penetrating the side of the ship may be prevented from continuing its passage into the vitals—that is, engines and magazines; secondly, that sufficient "head-space" may

Armoured Decks.

be given to the engines and machinery in the centre line of the ship, whilst at the sides the deck is carried well below the water-line, to prevent the possibility of projectiles entering below its edges. Armoured bulkheads divide a vessel into transverse sections, and, in the case of our latest ships of the *Dreadnought* type, the main bulkheads extend from keel to main-deck without a door. This is the finest insurance of the floatability of a ship that can be provided. The *Dreadnought* and her sisters have lifts provided to enable the crew to go up and down between the various decks. In addition to the bulkheads, we have many other protective items of a ship's construction, amongst them cofferdams—half-bulkheads into which canvas, oakum, or other matérial can be jammed during an action to limit the flow of water across the deck should one of two compartments so divided be pierced. Then there are armoured scuttles and gratings, and slanting plates around the uptakes of the funnels between decks to prevent damage here, and the subsequent filling of a deck with smoke and gases from the furnaces.

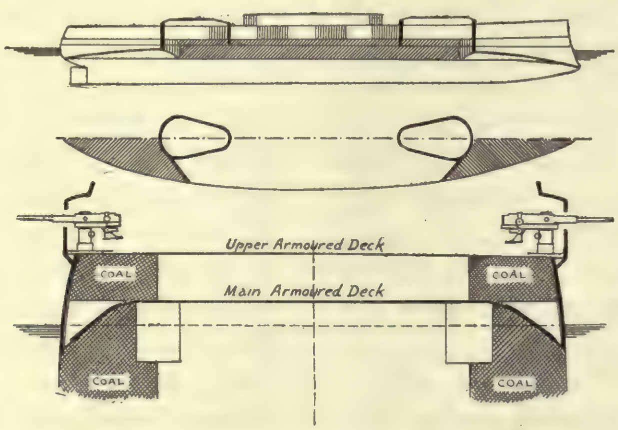
With every improvement in armour there has been an almost immediate improvement in the shell to attack it. As far back as 1894 Messrs. Thomas Firth and Sons of Sheffield suggested "capped shells"—that is, a shell fitted with a cap of comparatively soft metal which on impact would break up, star the plate attacked, and allow the shell proper to apply its whole force in piercing the plate. This firm, in December 1907, gave a new 12-inch common shell a trial against a 9½-inch Krupp cemented plate, fitting the projectile with a cap. It

Capped Shells.

went through the armour without any trouble. A "Heclon" capped shell, made by Messrs. Hadfield, fired at Shoeburyness on January 3, 1908, perforated a 12-inch K.C. plate, 3 feet of oak backing in three thicknesses, a row of sacks filled with cement, 24 feet of sand, dented two steel floor plates of the butt, and was, nevertheless, eventually recovered undamaged except for the loss of its cap. This showed, amongst other things, the enormous amount of energy remaining in the projectile after perforating a plate. Of course, the results on the trial ground are not likely ever to obtain at sea. In tests the plate is but a short distance from the gun, the range is constant, both firing-platform and target are stationary and fixed, the plate is shored up behind, and is at absolute right angles to the line of fire—in fact, everything is in favour of the gun. At sea the target will be moving horizontally, and, if the vessel be rolling at all, vertically also. Moreover, the plates are curved to the tumble-home of the ship's side, therefore the projectile will strike a rounded surface. Finally, everything suggests that the gun will, at sea, fire at plates facing it more or less obliquely. So superior to armour did the shell prove, however, that many experts believe that the highly-efficient armour-piercing projectiles of the present time, furnished with caps, have largely robbed Krupp cemented armour of its protective qualities. It is considered, indeed, that a reaction must set in shortly in favour of armour having exceeding toughness rather than mere surface hardness.

A new steel, known as "Era" steel, recently brought out by Messrs. Hadfield, enters largely into the protection of all our latest armoured ships, from the *Lord Nelson* class onwards. Last year this firm produced a plate which they called the "cap-deflecting plate." Its outer surface is "waved" or indented, giving it the appearance of corrugated iron. Under certain conditions, the particular form of the surface of this improved "Era" armour causes the cap to be displaced or deflected before it has time to give the necessary support to the projectile, as occurs when ordinary flat-surfaced armour is attacked.

Suggestions have recently been made by Signor D'Adda to armour warships with concrete. That this material will be used in place of steel, at least not for a very long time to come, cannot be believed, yet the suggestion is worthy of note. Could a composition, efficient, durable, and impenetrable, be discovered, the building and equipping of warships would be simplified and accelerated, and much of the present expense, due to the tedious treatment of modern steel armour, would certainly be saved.



DIAGRAMS TO SHOW THE ARRANGEMENT OF A BATTLESHIP'S ARMOURED DECKS.

THE ARMAMENT OF A BATTLESHIP.

BY ALAN H. BURGOYNE.

LIFTING A 12-INCH GUN ON TO A BATTLESHIP. (*Photo, S. Cribb.*)

THERE is but one reason for which a warship exists — to fight. The means of carrying on a contest with a hostile vessel are of three kinds —guns, the ram, and torpedoes. With the first only of these we propose to deal in this article. It is the writer's wish to elucidate those numerous perplexing problems presented by a casual visit to a warship. Many civilians are entirely in the dark as to the difference between main, secondary, and tertiary armaments. Others, again, cannot grasp readily the effect of increased length, increased muzzle velocity, etc., in guns of similar muzzle diameter. Let us therefore tabulate types of guns in their three main sections.

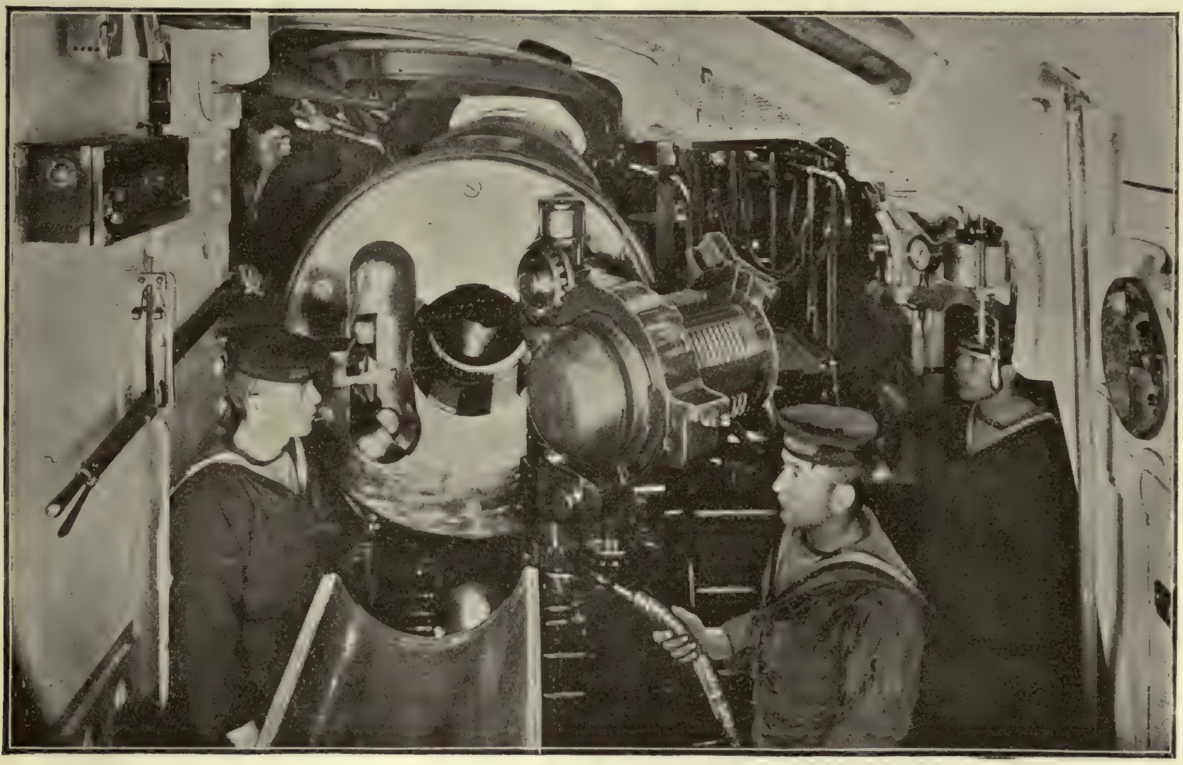
Main Armament.

1. *Main Armament.*—Referring solely to battleships, the guns deemed worthy of inclusion in main armaments range from the 9·2-inch to the 16·25-inch gun. (The figures here quoted give the "internal diameter" or "calibre" of the barrel of the gun, the method of measurement generally accepted throughout the world.) Between these two sizes or types is a range of "calibres," differing in weight of weapon, weight of shell, power, and efficiency. These are the 16·25-inch, 13·5-inch, 12-inch, 10-inch, and 9·2-inch. Foreign nations have a range very similar to this. The leading German guns of to-day are the 11-inch and 9·4-inch. The Americans have 13-inch and 14-inch guns. It is not intended here, however, to deal with foreign weapons, but to explain in simple form those commonly used in the British Navy. In armoured cruisers guns of lesser calibre (7·5-inch and 8-inch) are reckoned as the "main" armament, though of secondary

importance as judged by the battleship standard. Now, the business of the main armament is to "smash" or "sink" the enemy's ship. Its blows should be paralysing, pulverising, and definite; hence the tendency, as battleships increase in displacement, is to augment the size of the gun. For with every increase in the calibre of a gun there is a proportionate increase in the weight and destructive power of the shell it fires.

2. *Secondary Armament.*—After the fleets have joined issue at distances commencing with 10,000 to 12,000 yards by means of their heavy, far-ranging guns, the natural conclusion is (or was) that they would eventually approach or "close" each other, in which event a judicious hail of shell flung rapidly by lighter guns might well complete the demoralization already commenced by the larger weapons. These smaller guns fire much more rapidly than do their big brothers, hence their name of quick-firing guns. Their calibres range from the 4-inch Q. (Q = quick-firer) to the 8-inch Q.; and between these two sizes we find the 4·7-inch Q., 5-inch Q., 6-inch Q., and 7·5-inch Q., with, in foreign types, the 4·1-inch Q., 5·9-inch Q., 6·7-inch Q. (German and French), and 7-inch Q. (United States).

Secondary Armament.

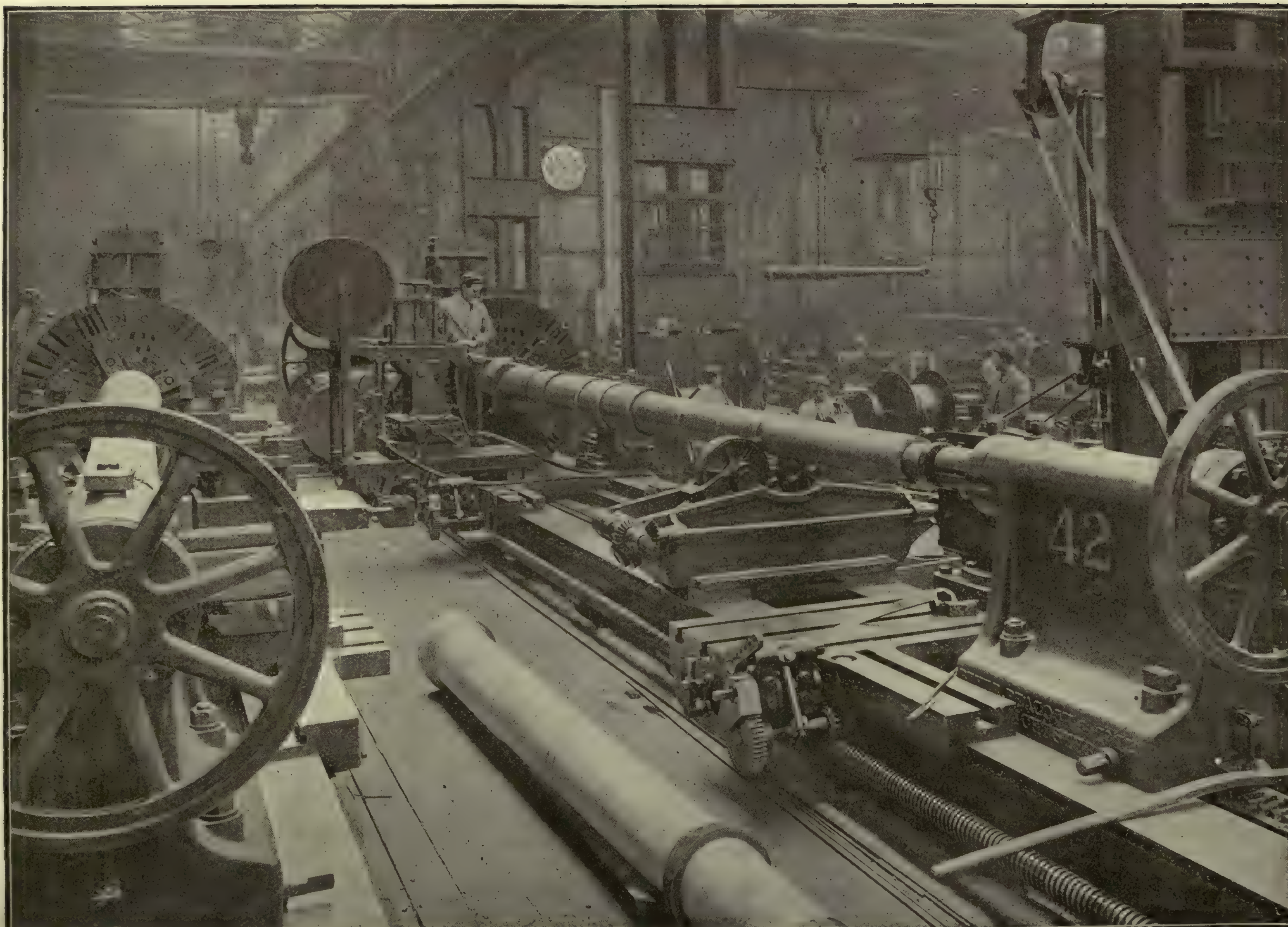


INSIDE A BARBETTE, SHOWING THE BREECH ACTION OF A 12-INCH GUN. (*Photo, Gale and Polden.*)
Note the "interrupted screw" device by which the breech-block grips the gun.

3. *Tertiary Armament.*—Lastly, we have the guns of the tertiary or anti-torpedo-craft armament. They range from the rifle-sized many-barrelled machine-gun to the 4·7-inch Q., or even the 5-inch Q. It will be noticed that there are certain calibres that enter, perforce, into two categories.

Tertiary Armament.

It is proposed to take a typical battleship, the *King Edward VII.*, and describe her



WINDING WIRE ON TO A 12-INCH GUN. *(Photo by courtesy of Messrs. Vickers Sons and Maxim.)*

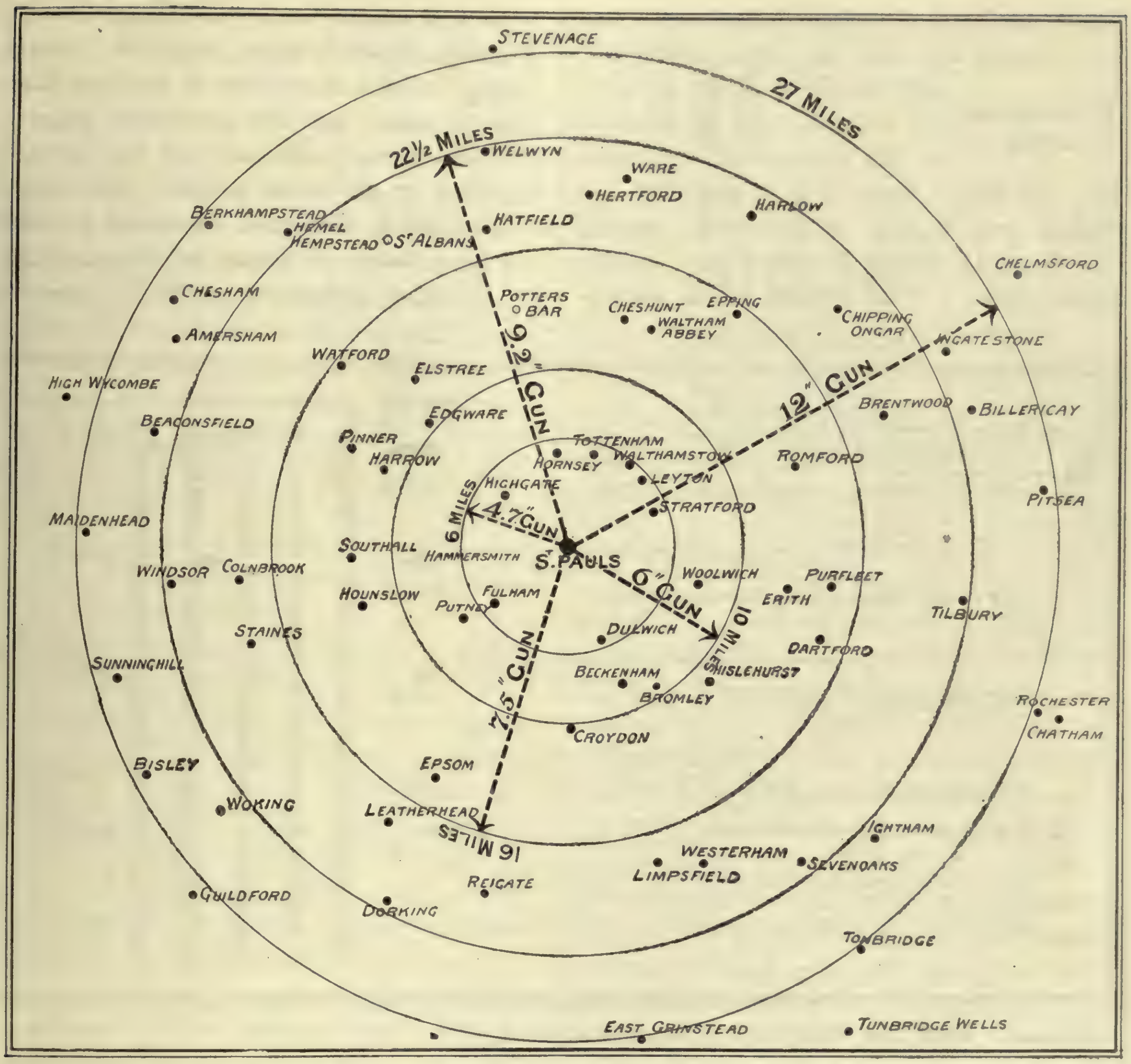


DIAGRAM TO SHOW THE APPROXIMATE MAXIMUM DISTANCES TO WHICH GUNS OF VARIOUS CALIBRES COULD FLING A SHELL FROM THE VICINITY OF ST. PAUL'S CATHEDRAL.

The range of each type of gun is shown by a dotted arrow reaching to a circle at its point.

armament in detail. The eight vessels of this type carry forty-eight guns each, divided into the three classes as follows :—

Four 12-inch...............	Main armament.
Four 9·2-inch	
Ten 6-inch Q.	Secondary armament.
Fourteen 12-pounder Q.	Tertiary armament.
Fourteen 3-pounder Q.	
Two machine-guns.......	

Taking first the 12-inch guns. These are described as Mark IX., 40 calibre, wire-wound breechloaders. This, in plain English, means that they are the number nine pattern of 12-inch guns, have a barrel forty times the length of its internal diameter, are made up on the wire-wound system, and, finally, are loaded at the breech or back end of the gun and not by the muzzle.

Wire-wound construction distinguishes British guns from the majority of those mounted in foreign ships, notably German, which are

"built up" of a series of hardened steel tubes placed one over the other while hot, and allowed to shrink by cooling to a position of security.

Wire-wound Guns.

In the wire-wound method a tube, the real "barrel" or "bore" of the finished gun, having a thickness varying from 1 to 1¼ inches, is placed on a slowly turning lathe. Wire ribbon of a rectangular section is then wound carefully round it, coil by coil, until a sufficiency for the agreed pressure-strength has been reached. A retaining band is placed over the last coil to keep it in place, and the whole is covered with a steel jacket, which protects it and also gives longitudinal strength to the piece. The wire as it is wound on is subjected to a very high tension. Upwards of 120 miles of such metal ribbon enters into the construction of a modern 12-inch gun. The inner tube or barrel is "rifled" along its entire length—that is, grooves are cut into its surface with a circular inclination similar to that of spiral stairways. The grooves, by gripping the soft copper rings or "driving bands" affixed to the rear of the long shells, give to these last the twist that helps to maintain a rigid adherence to the direction imparted by the initial impulse. The muzzle of the gun is thickened somewhat to resist the final strain of release as the shell and its following propellant gases fly from the tube. Into the rear of the bore of the gun, the last few feet of which are of larger diameter for the better reception of the cordite or powder, a "breech-block" or door is placed.

The Breech-block.

A breech-block is of conical shape, and the threads or screws whereby it "engages" with the body of the gun itself, and so closes the firing chamber before the discharge, are so interrupted that the entire locking of the device is accomplished by one-twelfth of a circle's turn. The opening and shutting of this breech-block is effected by a wheel which, in one

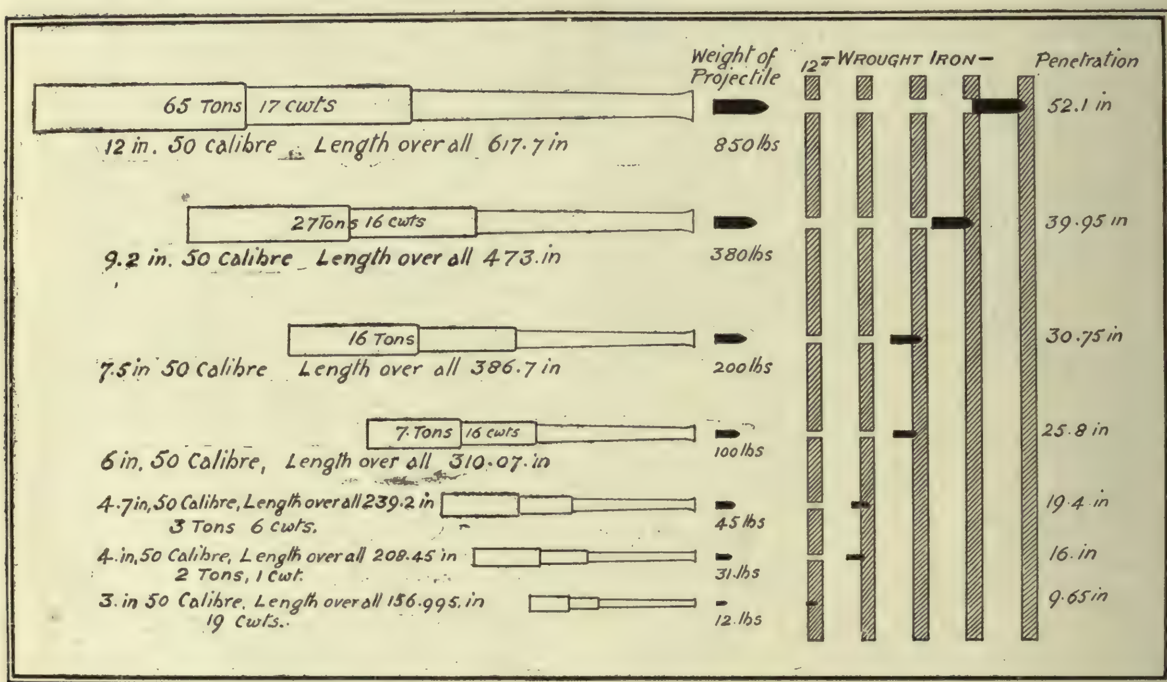


DIAGRAM TO SHOW THE PENETRATIVE POWERS OF GUNS OF VARIOUS CALIBRES.

continuous movement, first rotates and unlocks the breech-plug, and then swings the entire mass clear of the gun, leaving it ready for sponging out and for the insertion of another shell. The time required for opening the breech of a modern 12-inch gun is 3·9 seconds by mechanical gear, and 6 seconds by hand; for shutting, 4·5 and 7 seconds respectively. The backward force of the explosion of the powder charge within the bore itself is taken up by what is called an "obturator"—a plastic pad of asbestos or similar material protected by metal rings, seated in a cone formed at the rear of the powder chamber, and secured to the breech-screw by means of a mushroom-headed bolt and nuts. In it is arranged the electrical firing device explained below.

Latest Types of 12-inch Gun.

The Mark IX. gun carried by the *King Edward VII.* weighs 50 tons without its mounting, and is 496½ inches long over all. The length of the bore, or rifled part of the barrel, is 40 feet. The cordite charge weighs 211 lbs., the shell 850 lbs. The speed at which this mass of metal leaves the muzzle is 2,580 feet per second, and the energy at the muzzle in foot-tons is 39,280, or more than sufficient to lift two *Dreadnoughts* a foot off the ground. The power of this piece of ordnance may be measured by penetration. It is calculated that at the muzzle this gun would drive its shell through 42 inches of wrought iron; at 3,000 yards through 32 inches of the same metal. This gun led the world four years ago; yet since then we have had the Mark X., 45 calibre gun, and have already passed it by for the Mark XI. of 50 calibres. The Mark XI. weighs 65 tons 17 cwt. without its mounting, and is 617¾ inches long. The bore has a length of 600 inches, or 50 feet; and though the weight of the shell remains at 850 lbs., the cordite charge has increased to 344 lbs. The velocity of the projectile at

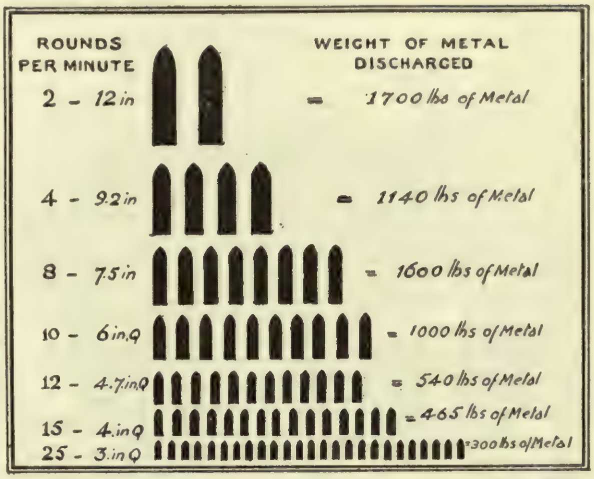


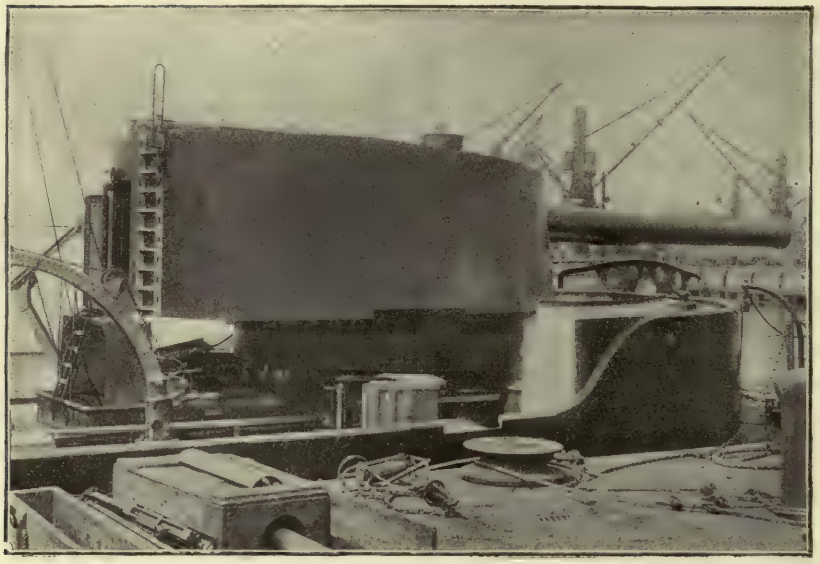
DIAGRAM SHOWING NUMBER OF ROUNDS FIRED AND WEIGHT OF METAL DISCHARGED PER MINUTE BY GUNS OF VARIOUS CALIBRES.

the muzzle is 3,010 feet per second, and the muzzle energy has been augmented to 53,400 foot-tons. The most noticeable difference, however, is in the muzzle penetration of wrought iron, which has now risen from 42 inches to 52·1 inches—an immense advance. It is calculated that this weapon has a maximum range of 25 to 27 miles.

The stupendous recoil of a modern gun is absorbed most wonderfully by a combination of pneumatic and hydraulic resistance cylinders placed beneath the gun-carriage. In the latest electrically operated guns the weapons themselves are run out subsequent to the recoil by what is called a "counter-recoil." This is either a pneumatic cylinder or a strong battery of springs. Our own Admiralty is making experiments with both systems in the armoured cruiser *Invincible.*

Gun Mountings.

These large guns are placed on their mountings in "cradles" or steel bearings curved to the circumference of their outer surfaces. Square steel "thrust rings" welded to the exterior jacket, and forming an integral part of it, engage with slots cut in the cradle. When mounted in pairs in barbettes or turrets, guns are designated "left" or "right,"



9·2-INCH GUN AND BARBETTE ON TEMPORARY MOUNTING FOR TESTS.
(*Photo, Gale and Polden.*)

according to the place they occupy, and are fitted on the outer side in each case with the mechanism required to operate them.

The explosive charge is to-day very different from the old black powder of years ago. The ordinary black cubes were first replaced by prisms of brown material known as "cocoa" powder. Then came the demand for energy without smoke. A propelling agent having the character desired was discovered by Professor Abel; it is named "cordite," from its resemblance to gray cord. Now, cordite contains no less than 58·3 per cent. of nitro-glycerine, and nothing is so harmful as this compound to the surface of the bore of a gun. Consequently the inner barrels of guns wear out quickly if this powder be used constantly. "Wear" falls under two heads —"erosion" and "wash." Erosion is the eating out of the surface of the bore by the charge pure and simple. Wash is caused by the rush of gas between the projectile and the bore wherever a space is found. Erosion being due to gas moving rapidly at a very high temperature and under pressure, the only remedy known is to reline the gun from time to time. Wash can be remedied to a large extent by the means of tight-fitting "gas-checks," and, as the bore automatically gets enlarged, by fitting driving bands of extra thickness on the shells. In peace time, to save the bores of large guns, their barrels are fitted with tubes firing a 12-pounder or 6-lb. shell.

Erosion and Wash.

The sighting apparatus of all guns is placed to one side, and is entirely independent of the vertical movements of the gun. The charge itself is fired by electricity. On a platform so unstable as that of a ship, it will be readily understood that any delay in discharging a gun when it bears on an object would probably result in a miss. Electricity, being instantaneous, entirely obviates this difficulty, and firing is now accomplished either by pulling a trigger similar to that fitted to a rifle or by merely pressing a button. In either case an electric circuit is closed in wires which lead to the breech-piece of the gun and terminate in a fine platinum filament of high electrical resistance surrounded by a small amount of fulminate or other high explosive. The current heats the filament, ignites the fulminate, and through it the main powder charge. This method is eminently suited for the firing of a simultaneous broadside from a central point of control.

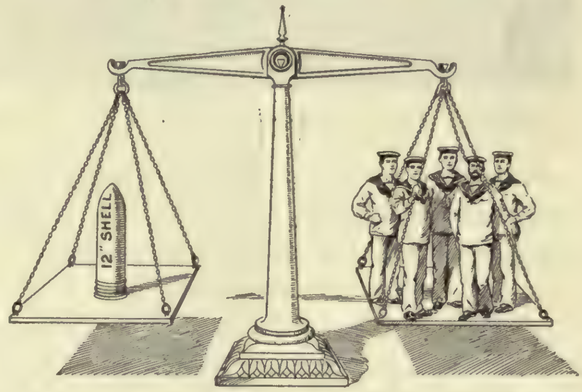
Firing a Gun.

As to the mounting of these monster weapons, they are placed in what is called a "barbette," and are protected by the "barbette shield." The barbette is the modern equivalent to the obsolescent turret. A turret is a thickly armoured circular struc-

ture, through holes in which the muzzles of the guns protrude. This revolves on roller bearings around circular steel channels in the deck, and the guns go round with it. The barbette differs in this that it is a fixture, and forms part of the structure of the ship herself—a very immense advantage. The guns are placed upon a revolving platform *within* the armour plates forming the barbette, and it is this inner turn-table, to which is also fixed the barbette shield, that carries the guns round on their various arcs of bearing. (We should note in passing that turret is now the generally accepted term for a gun mounting, including the modern barbette.) Beneath this barbette chamber or turn-table is a working-chamber, 9 or 10 feet in height, which forms the intermediate position in the loading system. From this chamber a thick steel tubular trunk descends directly through the decks to the ammunition rooms, or near to them. (See illustrations on page 447.) This encloses the "ammunition hoist," up which projectiles and powder charges are sent into the barbette along continuous chained "lifts." In ships fitted with turrets, the guns had to be brought back to a particular position before reloading could be accomplished. To obviate this necessity, which takes, it need hardly be said, a considerable time, and necessitates the fresh laying of the gun after each discharge, the modern ammunition trunk is attached to and revolves with the gun platform. As a result the weapons can be loaded at any point on the arc of training and at any elevation. The powder charges are arranged to be loaded in cages at the magazine floor, which is, as a rule, immediately over the shell magazine. Their weight is such that they can be handled easily. The charges are placed in suitable receptacles attached to the armoured hoist, in readiness to be transferred to the lifts or hoist as they come into position for loading. Where there are two guns in a turret, independent ammunition loading hoists are provided. Tell-tale dials are also fitted in the working chamber beneath the barbette to let the operator in charge of the ammunition supply know where the hoists are at any particular moment. The gear is all interlocked, so that there is no possibility of premature hoisting or of jamming. In the roof of the barbette shields are fitted raised

Turrets and Barbettes.

Ammunition Hoists.



A 12-INCH SHELL WEIGHS 850 LBS., AND WOULD COUNTERBALANCE FIVE 12-STONE MEN.

steel "boils," with small eye-slits. These are the lookout or sighting hoods.

Three sighting positions are usually provided in twin-gun mountings. At the centre position between the guns there is a sight for each gun; at the side positions a sight is provided for the gun on that side only. The training and elevating of the guns are, of course, under complete control from these positions. The elevation allowed by the gun aperture in a barbette shield of a modern 12-inch gun is 35 degrees, with 5 degrees depression, making 40 degrees in all. Since a bare 15 degrees represents a range of 18,000 yards, the maximum given is more than sufficient for any possible need that might arise. The entire weight of a pair of 12-inch guns, barbette, shield, and mounting, exceeds 450 tons.

A GROUP OF 12-INCH SHELLS. (*Photo, Gale and Polden.*)

A word as to cost. We are dealing now with the mounting and machinery only of the larger guns. In the *Majestic* class—ships of 14,900 tons, and now fifteen years old—the pair of 12-inch mountings, containing four 12-inch guns and placed fore and aft of the ship along the keel line, cost £49,000, or about 5 per cent. of her total cost. The *King Edward VII.* has six large gun mountings—two for paired 12-inch guns, four for single 9·2-inch guns. The cost here was £220,000, or about 15 per cent. of the total cost of the ship. In the *Lord Nelson* class the mountings have risen to eight, and represent £440,000, or 27 per cent. of the cost of the ship! This last figure is interesting, for, as a comparison with the *Dreadnought* will show, single guns in barbettes increase the cost out of all proportion to the military value. The *Dreadnought* has five gun emplacements mounting ten 12-inch guns in pairs, and yet the price of her gun mountings was only £365,000, or 21 per cent. of her total cost. The *Lord Nelson* mounts but four 12-inch guns paired, the remainder being ten 9·2-inch weapons—eight paired and two mounted singly.

Cost of Mountings.

A well-known expert has analysed the results of improved firing in recent years. In the case of the larger guns of 10-inch and 12-inch calibre, the accuracy is three times greater than it was ten years ago. The average for the whole fleet is now 0·61 hits per minute per gun (and it is only the *hits* that count), as against 0·23 under conditions then prevailing. The improvement in the case of the 9·2-inch gun, the most popular weapon in the service, is even more remarkable, the figures having risen from 0·32 hits to 3·25 hits a minute. With the 6-inch quick-firing gun also the advance is striking. Ten years ago the hits per minute totalled only 1·11, but now the score throughout the service stands at 5·93 hits. When one considers the maximum results and, therefore, the degree of accuracy which may be achieved by perfection in mechanism and efficiency in *personnel*, the gain is still more remarkable. With the 12-inch guns two hits per minute have frequently been made, and four hits per minute are not uncommon with the 9·2-inch projectile, even under severe conditions of firing.

Improved Gunnery.

All that has been said of the 12-inch guns applies generally to every weapon entering into the category of "main armament." We may just notice, however, that the four 12-inch weapons of the vessel under review, the *King Edward VII.*, are mounted in pairs at either end of the ship. The four 9·2-inch guns are mounted singly in barbettes on the upper deck at the four corners of the superstructure.

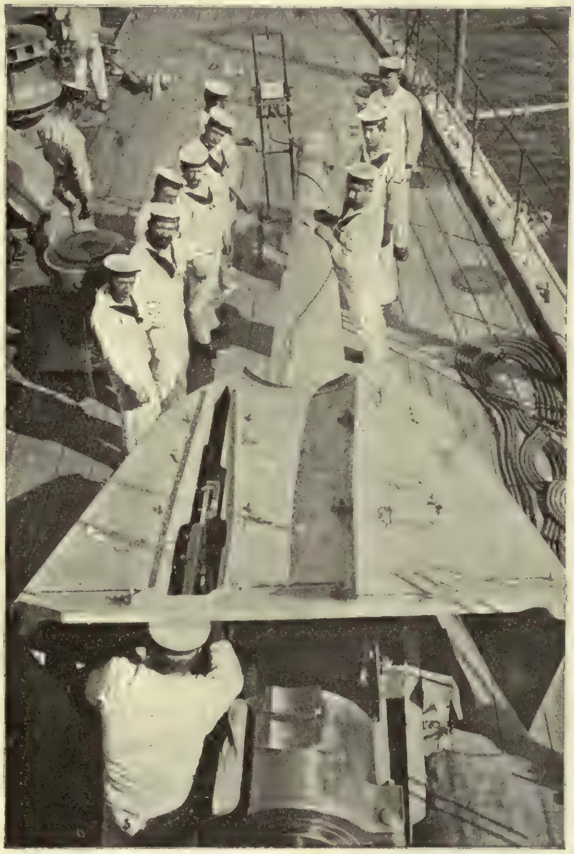
Before leaving the main armament of battleships, we will describe the most powerful gun in the world. This, the 16-inch United States

army gun, though not the largest ever produced, weighs 126 tons exclusive of mounting, and is 59 feet long. It uses a projectile weighing 2,300 lbs., as compared with the 850-lb. shell for the British 12-inch gun. With a charge of 640 lbs. of nitro-cellulose powder, and a chamber pressure of 17¼ tons to the square inch, the shell attained a muzzle velocity of 2,306 feet per second and a muzzle energy of 84,880 foot-tons, as against 54,500 foot-tons for the British 16·25-inch 110-ton gun! The penetration could only be guessed, but any projectile, even an armour-piercing shell with a large bursting charge, would, fired from this gun, go clean through the thickest belt armour carried by warships to-day at from 5,000 to 6,000 yards' range. The disadvantages of a gun of this size are that it can fire but one shot every three minutes, and that its weight and cost are excessive.

A Colossal Gun.

We now reach the secondary armament of the *King Edward VII.*, the ten 6-inch guns. These are mounted in casemates. A casemate is a small room or gun-house formed within the sides of the ship. Its outer face is protected by steel plates of thicknesses varying from 4 to 7 inches, according to the class of ship, and its enclosing walls at the back are made of splinter-proof sheets up to 2 inches in thickness. These gun-houses are separated entirely one from the other. Another method of mounting the secondary battery is that adopted in the Japanese battleship *Mikasa;* this is the "armoured battery." Here the entire side of the ship is sheathed in armour, and the guns are placed in a row behind it, being separated by splinter-proof partitions. The value of the secondary armament is a matter for dispute, but, whatever the future may bring forth, the large majority of ships in commission to-day carry one.

6-inch Gun.



"THE DOTTER"—A SMALL MOVABLE TARGET CONNECTED WITH A GUN, AND MARKED ELECTRICALLY BY A PENCIL.

The correctness of the gun-layer's aim is shown by the pencil when the trigger has been pulled.

(Photo, S. Cribb.)

The 6-inch gun is a weapon firing a 100-lb. shell, a projectile so easily handled that ten and eleven of them have been shot off in a minute, and the same number of hits secured. The 6-inch guns of the *King Edward VII.* weigh 7·4 tons, and have a total length of 269½ inches. The velocity of the shell on leaving the muzzle is 2,750 feet per second, and the charge of powder to propel it weighs 20 lbs. The manipulation of this gun is as follows: At the side of the weapon is a curved wooden

shoulder-piece, movable in all directions, and controlling directly the gun itself, which, being accurately balanced, can thus with little exertion of the body be freely moved both horizontally and vertically. The gunner stands at this shoulder-piece, which is unaffected by the movements of the gun when fired, and casts his eye along the sight. One hand works the elevating gear and training wheel, whilst the other grasps the pistol-shaped trigger. The mounting itself is a central-swung pivot, and, being on live rollers, turns with hardly an effort. The recoil of these lighter guns takes place within the casing, which envelops them like sleeves, and forms the carriage. In the smaller guns of 4-inch calibre, etc., the base of the brass cartridge case used takes the place of the obturator already described, and effectually seals the breech when closed. Of course, advancing to a projectile weighing 100 lbs., with a corresponding increase in the weight of the charge, involved having a brass case of almost unwieldy dimensions. As weight of ammunition is an important consideration in a warship's equipment, and handicaps rapid handling, the brass case is now dispensed with in the 6-inch Q., and the obturator of the larger guns is fitted to their breech-blocks, the shell and charge being placed separately into the breech.

When the armoured cruisers of 9,800 tons (known as the "County" class, by their being named after British counties) were designed,

The 6-inch Mountings.

it was decided to place a pair of 6-inch quick-firing guns in a turret forward, and another pair aft. The turret for twin-guns is essentially a British idea, but we had never before built a closed revolving gun-house for a smaller gun than the 9·2-inch. The main objection to this method of mounting light guns is that the rate of fire is reduced somewhat, for the clear space about the guns is not great, and does not make for rapidity of service. The turret for the 6-inch guns is 4 inches thick, as is also the barbette in which it stands. This thickness, too, protects the working chamber beneath the turn-table, in which are situated the electric motor and other parts of the training gear. One hundred and thirty-two projectiles are stored in the barbette for the immediate service of the guns. The charges are brought up the central ammunition tube by an endless band hoist, worked by an electric motor at the foot of the hoist. This main hoist or lift normally delivers its cartridges to the left, but by an ingenious arrangement of an auxiliary band hoist running at higher speed every alternate cartridge may be delivered to the right. If desirable, projectiles may be placed in the hoist alternately with or in lieu of cartridges. The cartridges and projectiles are loaded into the guns independently by hand.

Each gun has a separate sighting position, with handles conveniently placed for working the training switch to the electric training gear, and for elevating by hand. Hand training gear is available if necessary. With electric training the turret can be swung through 360 degrees in 30 seconds, and with the hand gear in 1 minute. The guns can be elevated, loaded, and fired independently, but must, of course, be trained together.

The latest development of the 6-inch gun is the 50 calibre weapon produced by Messrs. Vickers Sons and Maxim, the world-famous

The Latest 6-inch Gun.

gun manufacturers and ship-builders. This weapon weighs 7 tons 16 cwt., is 310 inches long from muzzle to breech-block, and develops a muzzle energy of 7,056 foot-tons. The muzzle velocity is 3,190 foot-seconds, an advance of nearly one-sixth over that of the *King Edward VII.* guns.

The "tertiary" or anti-torpedo armament of the *King Edward VII.* consists of fourteen 12-pounder Q. and a similar number

of 3-pounder guns. They fire respectively shells of a weight shown by their designation.

Anti-torpedo Craft Armament.

In vessels of the improved *Dreadnought* type, sixteen to twenty 4-inch Q. are carried; for of course the small weapons mounted in the *King Edward VII.* would, in the absence of a serious secondary armament, leave such immense vessels practically at the mercy of torpedo craft. The proper calibre of anti-torpedo guns is a matter about which the naval Powers of the world are by no means unanimous. The United States mount weapons of 5-inch calibre; Germany, according to various authorities, 6-inch and 4·1-inch guns; while France holds to the multitude of smaller weapons. Japan, again, retains her secondary armament, whilst bringing the main armament of her latest battleships, the *Kawachi* and *Settsu*, up to the standard of Europe.

One thing at least is certain—battleships, acknowledged to be the objective of the torpedo, will and must be provided with such an armament as shall counteract effectually the menace of destroyer or torpedo boat attack. The 3-inch (12-pounder Q.) was introduced to destroy torpedo vessels with a displacement in the region of 300 tons or under. This gun has remained where it started, except in the matter of muzzle velocity, though the boats which it was introduced to destroy have increased in size out of all knowledge.

No one would have dreamt of repelling the torpedo-gunboats of ten years ago, displacing as they do 800 to 1,200 tons, with projectiles of only 12 lbs. in weight; and yet to-day these same projectiles are expected to protect the capital ship from attacks by boats considerably larger and infinitely faster, and hence more dangerous. The necessity for a small gun firing a large number of shots per minute is

Need for Powerful Tertiary Guns.

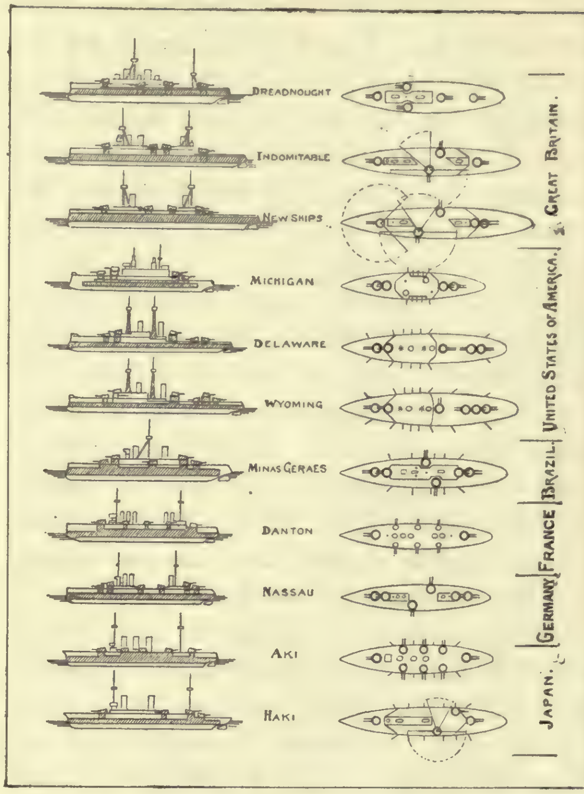


DIAGRAM TO SHOW THE ARMOUR AND DISPOSITION OF GUNS ON THE LEADING BATTLESHIPS OF THE VARIOUS NAVAL POWERS.

fast disappearing. The retention of the 3-pounder and 12-pounder gun as an anti-torpedo boat weapon cannot be sustained. A mere glance at the dimensions of the ocean-going destroyers *Ghurka* and *Swift* is sufficient to support the theory that future safety must be sought in a very much increased gun calibre.

	Ghurka.	*Swift.*
Length	255 ft.	345 ft.
Beam	25 ft. 7 in.	34 ft. 2 in.
Draught	8 ft. 10 in.	10 ft. 5 in.

What effect could a 4-inch Q. have upon the old battleship *Nile?* Obviously none, and yet she and the *Swift* are identical in length, and the latter shows rather more hull, and thus (though of but a sixth the displacement) appears a larger ship in side superficies. The fact is, the resisting power of the modern destroyer has been much underrated, and

the destructive power of the 3-pounder Q., 6-pounder Q., 12-pounder Q., and even the 4-inch weapon, as much overrated; and the result of this discovery is seen in the influence it has had upon the recently-launched warships of Germany, the United States, and Japan. In the war between Russia and Japan the generally prevalent idea that a couple of 12-pounder shells would disable a destroyer or first-class torpedo boat, wherever burst, was disproved on many occasions. The most numerous engagements during the whole naval campaign were between the torpedo craft of the opposing nations, and the number of hits these small vessels could sustain without serious damage has been the subject of much wonderment ever since.

Accepting this, the advent of such vessels as the *Tribal* and *Swift* classes will necessitate a return to secondary batteries in warships before their prophesied abandonment has fully taken effect. The *Dreadnought* carried 12-pounder Q. only; the later ships have a 4-inch gun. The American *Michigans* carry the 12-pounder Q.; the *Delawares* and *Wyomings* will, as already stated, mount a 5-inch weapon. So by all the Powers is the truth being realized, and the 6-inch Q., or even larger gun, will return, not, however, as supporting the large guns of the main armament, but purely for defence against torpedo-carrying craft.

Before closing this article, an instructive word may perhaps be said as to the "disposition" of guns. So many people think that the number of guns carried by a warship is controlled either by the length, and, therefore, "room of side" displayed, or by the carrying capacity of the ship herself. Actually, the placing of the armament involves problems of the utmost intricacy. Thus there is first the mere length of the weapons to consider. Take a 12-inch 50 calibre gun. It is about 52 feet from muzzle to breech, and from the breech to the barbette shield there is a clearance of another 6 feet. Thus each pair of 12-inch guns of the latest type requires a "swinging" space of, at the least, 62 feet, allowing a 3-foot passage behind the barbette shield and a foot clearance between the muzzle and the superstructure it faces as it swings round. The next problem is that of "blast"—the vast disturbance of the air around the muzzle created by the discharge of a shot. So intense is this that many a time decks have been severely ruptured. It is a fact both curious and not generally known that the blast does not cause a depression in the deck directly beneath the muzzle, but it tends rather to raise a "bubble" in it. Hence it is not support that the decks require, but holding down from below. The reason of this seeming anomaly is simply explained: the gases composing the blast are at a super-terrific heat, and in their passage utilize all the combustible properties of the air, and form a momentary yet powerful vacuum directly above the deck. Where guns fire at all angles across decks, steel "flash-plates" are frequently sunk in the floor around a radius corresponding to the training arc of the guns.

The Disposition of Armament.

The last and governing difficulty, yet one which is dovetailed in with the first two, is the necessity for obtaining an all-round fire, and, at the same time, the maximum concentration of such fire on the two broadsides. Here constructors are at once faced by a hundred contending and hostile factors. Superstructure there must be, to support the boats, conning tower, fighting position, and masts, funnels, etc., though the natural tendency is to reduce all such "top-hamper" to the minimum dictated by necessity. Then the position of the magazines comes into conflict with the other considerations. The engines and boilers take up an immense

Difficult Problems.

space, and the engineer deserves as much recognition in designing a ship as does the gunner. For of what use are the guns if you have not the means of getting at the enemy? With all these problems balancing one against the other, it is not surprising that the ideas of various constructors have diverged along entirely different lines. A plan is reproduced on page 415 of the disposition of the guns of the latest type of battleships throughout the world. Though we may lose in concentration of broadside fire, the method adopted in the *Dreadnought* type suggests advantages to which no other design shown can well lay claim.

Two particular methods may be mentioned and described. To place guns *en echelon* is a British invention which appeared in our

Echelon—

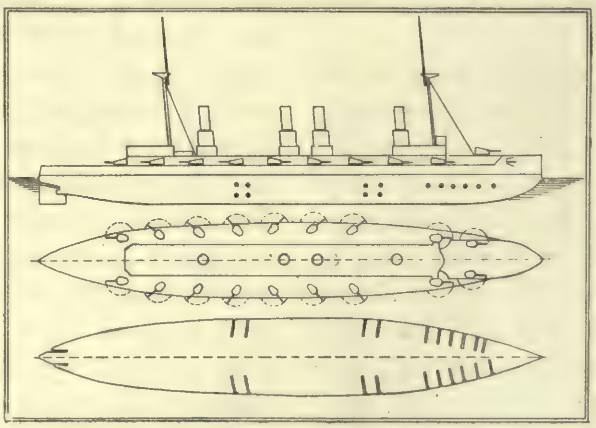
battleships twenty-five years ago. By this system two turrets are mounted diagonally athwart-ship in the centre of the vessel in such a manner as to give all four guns an arc of training upon both broadsides, and along the keel line both forward and aft. The *Invincible* class of cruiser is a fine example of the application of this system. The other idea is "superposition" of turrets. In this case one pair of guns is mounted at a higher level than and directly behind another pair in such manner as shall allow them

And Superposed Systems.

to fire over the latter, and give to all four guns the same arc of training. So far we have avoided this system, but it will make its appearance in the *Hercules* and *Colossus* class for the first time. The American Navy adopted it years ago, and, though their early experiments were not altogether successful, the experience gained has helped them to appreciate more thoroughly both its advantages and disadvantages.

Enough has now been said to lay bare many of the complications of a warship's gun power. True, battleships only have been discussed, but the greater here includes the less, whatever be the type, and that which has been said of the one applies with equal force to the other.

A SUGGESTED FRENCH DESIGN FOR A LARGE HEAVILY - ARMOURED TORPEDO VESSEL, FURNISHED WITH SIXTEEN QUICK - FIRING GUNS AND THIRTY UNDER - WATER TORPEDO TUBES.



Such a vessel, dashing among battleships, and projecting torpedoes in all directions, would be an exceedingly formidable antagonist.

THE DEVELOPMENT OF TORPEDO CRAFT.

BY ALAN H. BURGOYNE.

WHEN, just over forty years ago, Captain Luppis of the Austrian Navy and his mechanic, Mr. Whitehead, completed the first automobile torpedo, probably not one man living realized to what extent its development would affect the evolution of the fighting ship. As a weapon it at first proved erratic, untrustworthy, and immature; but each month saw its mechanism improved, while each rebuff by incredulous naval committees augmented the enthusiasm of its inventors.

The necessity for approaching close to the ship to be torpedoed limited temporarily the size of the attacking boat carrying the new projectile, which in those early days had a range of but a few hundred yards; and then, as now, the smaller the distance at the moment of discharge, the better chance would there be of making a hit. Launches had already been utilized for work with spar torpedoes—mere bundles of explosives, cunningly fixed upon the end of a pole, the length of which was the limit of range—so what more natural than that slings should be fitted upon either side of such launches for dropping the new automobile torpedoes? These craft were small, speedy (for their day), and handy. They employed few men, and cost little.

Early Torpedo Boats.

Meanwhile the torpedo itself was developing. Its speed had been doubled, and its erratic characteristics checked by internal balancing mechanism of improved type. The Norwegians first emphasized the importance of the new weapon by ordering in 1873 from Messrs. Thornycroft and Company, then of Chiswick, a boat designed solely for torpedo work. With a displacement of 7½ tons and a length of 57 feet, she steamed 14·97 knots on the measured mile. In 1877, however, a spurt in specialized craft became evident both at home and abroad; for we then built our *Lightning* (also at Messrs. Thornycroft's yard), and the Russian Government ordered no fewer than a hundred similar vessels, many from German firms. The *Lightning* made 19 knots on trial, in place of the 18 knots contracted for; and, gratified by this excellent result, the Government placed orders in 1877 and 1878 for twelve further boats to steam 18·5 knots on trial. Messrs. Yarrow had by now entered the lists, and this firm, like Messrs. Thornycroft, took a first place in developing torpedo craft. In 1879 Messrs. Yarrow sent Russia the 100-foot *Batoum,* which, with 500 I.H.P., had reached over 22 knots. Progress was rapidly being made.

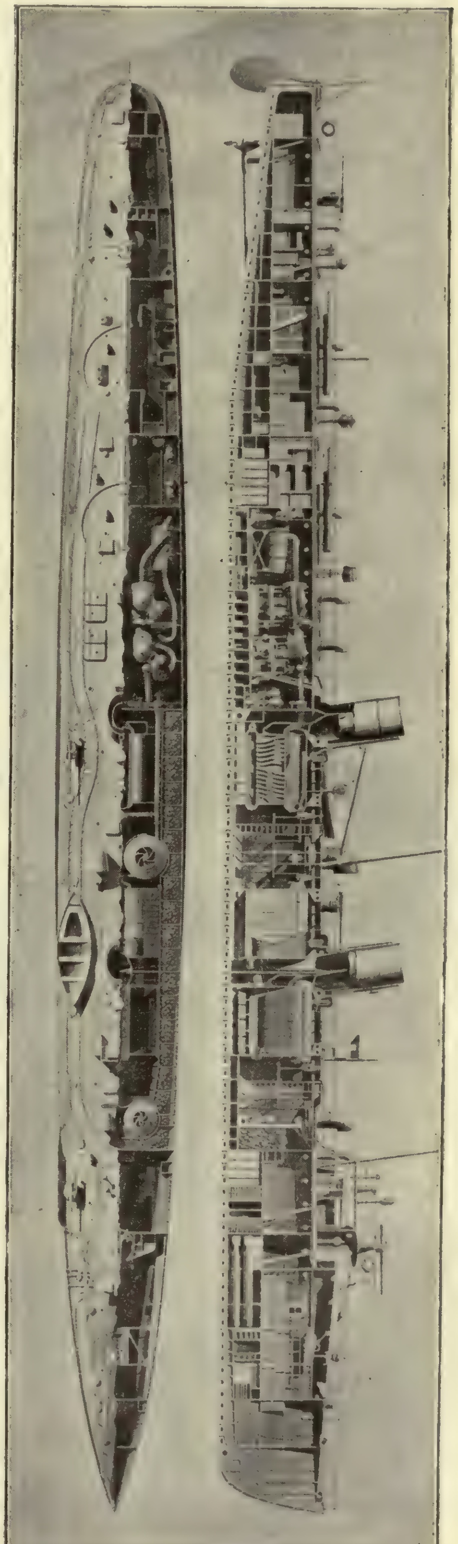
Every Power with naval aspirations, the United States excepted, was now feverishly constructing torpedo boats. The possibilities of the torpedo were perhaps even overestimated; and the boats, moreover, were cheap and easy to build. Speed was increasing annually, and 24 knots had frequently been reached and surpassed; moreover, the greater efficiency of the torpedo itself, and its longer range and higher velocity, removed much of the necessity for keeping its mother boat small. Hence designers, realizing that improvement in sea-keeping qualities, speed, engines, and armament meant a corresponding increase in displacement, were rapidly reaching the hundred tons.

The Torpedo Gunboat.

The obvious menace to a battle fleet in narrow seas from the swarms of these craft that might conceivably be hurled at it produced, in the first place, the torpedo net, a crinoline under-water defence for large ships; and, secondly, the almost inevitable torpedo catcher, or torpedo gunboat. This was a vessel of a displacement ranging from 500 to 1,000 tons, and possessing a nominal speed of 19 to 22 knots, and an armament of one or two heavy quick-firers of 4·7-inch calibre, several lighter weapons, and a few deck torpedo tubes. As a type it failed entirely to fulfil expectations, whether built for us or for foreign nations. It lacked speed, and even its greater displacement did not give it great stability in a sea-way.

The "Destroyer."

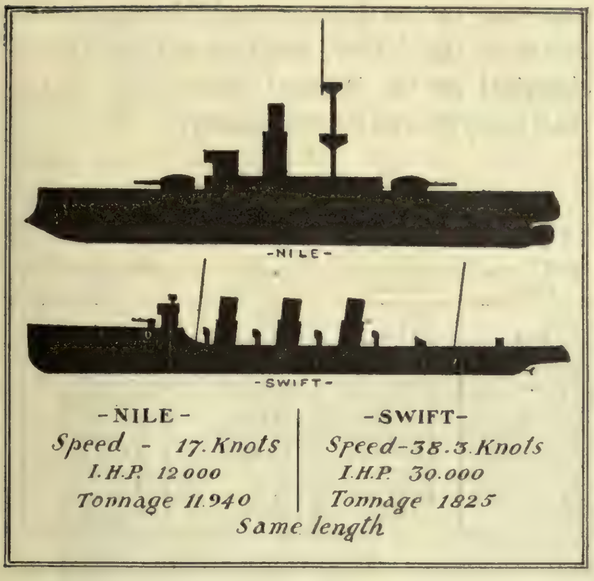
The failure had this much of good in it, however—it necessitated a change of policy along more practical lines. The British Admiralty at once took a wise course, and, bridging the evolution of, may be, a dozen years, placed their first order for "destroyers" (the name that has clung to the type ever since) in 1893. These craft, though but a quarter the size of the "ocean-going" destroyers of to-day, were yet more than twice



VERTICAL AND HORIZONTAL SECTIONS OF THE ITALIAN TORPEDO BOAT "NEMBO," SHOWING ARRANGEMENT OF MACHINERY, ETC.

H.M.S. "TARTAR" ON FULL-SPEED TRIAL.

This remarkable craft, built by Messrs. John I. Thornycroft and Co., made an average speed of 35·672 knots an hour during a six-hour trial run. Her highest speed (unofficial) is returned at 40·2 knots, or nearly 46 miles per hour, the record for the sea travel.
She displaces 870 tons, is 270 feet long, and develops 14,500 horse-power.

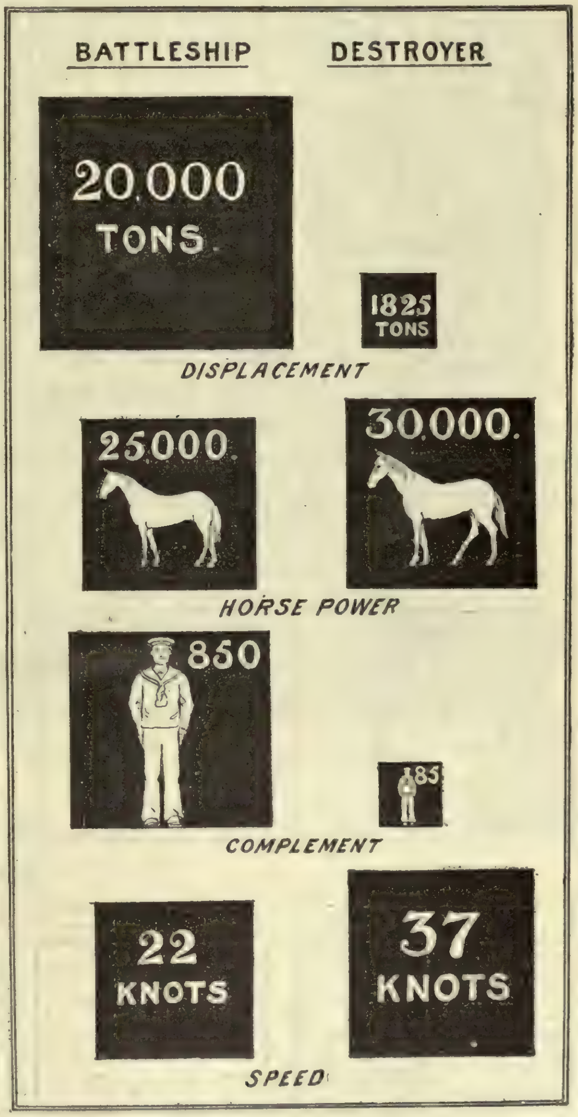


A DIAGRAM COMPARING THE LENGTH, TONNAGE, HORSE-POWER, AND SPEED OF THE OLD SECOND-CLASS BATTLESHIP "NILE" AND THE NEW DESTROYER "SWIFT."

the displacement of the torpedo boats they were designed to tackle. Let it be said here that the "destroyer" undoubtedly came into existence primarily as an antidote to the French torpedo boats, and that its success and speedy multiplication rendered at least a quarter of our neighbour's small craft, as well as most of those possessed by other European nations, immediately obsolete. Our policy of type initiation bore the excellent fruit that has ever fallen to our lot, as instance the most recent cases of the battleship *Dreadnought*, the armoured cruiser *Invincible*, and the *Tribal* class of destroyer. We promptly established a lead, and by doing so added vastly to our experience in the use of the new craft—an experience profiting naval officer and designer alike.

At this point the submarine boat—which will be dealt with separately—came prominently to the front. Its general acceptance by all navies did no little towards developing the secondary and tertiary batteries of ships of the line, and the menace it held out to its greater brethren received more and more definite recognition. Each advance in calibre of the tertiary armament has been induced by the growing—or possible—effectiveness of torpedo craft, whether destroyers, torpedo boats, or submarines.

As years advanced, destroyers developed along ordinary lines, until in 1897 such members of the British public as were present at the Naval Review were astounded by the meteoric appearances of the speedy



AN INTERESTING COMPARISON OF A FIRST-CLASS BATTLESHIP AND A DESTROYER.

The squares are proportional to the displacement, horse-power, complement, and speed of the two vessels.

little *Turbinia.* Since the advent of Mr. Parsons' astonishing yacht, destroyers have taken two distinct paths—those of the turbine and the reciprocating engine. It required no great intuition to realize that the latter type of engine was approaching finality, and that in the former would be found the motor of the future, until such time as the electrical or the internal combustion engine shall have proved its superiority.

The "Turbinia."

Turning to British turbine-driven craft we find the following :—

	Viper.	Cobra.	Velox.	Eden.	Mohawk.	Amazon.	Swift.
Date of Launch...	1899	1900	1902	1903	1906	1908	1907
Displacement	312 tons	400 tons	440 tons	540 tons	765 tons	890 tons	1,825 tons
Length..........	210 ft.	223 ft.	210 ft.	220 ft.	270 ft.	280 ft.	345 tons
Beam	21 ft.	20·5 ft.	23 ft.	23 ft.	25 ft.	26·5 ft.	34·25 ft.
Draught.........	8·2 ft.	8·5 ft.	8·5 ft.	8·75 ft.	8·9 ft.	8·25 ft.	10·5 ft.
Designed I.H.P. ..	10,000	11,500	8,000.	7,000	14,500	15,500	30,000
Designed Speed...	31 knots	31 knots	27 knots	25 knots	33 knots	33 knots	36 knots
Trial Speed.......	37·113 knots	36·63 knots	27·124 knots	26·22 knots	35·294 knots	36·8 knots.	38·3 knots
Armament......	1 12-pr. Q. 5 6-pr. Q.	1 12-pr. Q. 5 6-pr. Q.	1 12-pr. Q. 5 6-pr. Q.	4 12-pr. Q. —	3 12-pr. Q. —	2 4-in. Q. —	4 4-in. Q. —
Torpedo Tubes....	2	2	2	2	2	2	2
Complement......	66	62	63	70	60	68	—
Fuel Capacity	88 tons	107 tons	130 tons	130 tons	185 tons	185 tons	200 tons

Here we see the commencement of a new era. The *Velox* and the *Eden* are examples of the turbine "River" class, resulting from the *Cobra* disaster scare. Though engined on the Parsons principle, their hulls were so moulded that a speed of more than 27 knots could not be obtained. For three years the critics, both naval and civilian, waged war against the policy of low speeds, and the *Tribal* class, represented above by the *Mohawk* and *Amazon,* is the result. These vessels have a displacement equal to that of the later torpedo gunboats, and the *Swift* is the logical sequel.

Very Speedy Boats.

Whilst strides were being made with destroyers, torpedo boats also had been increasing their displacement, their speed, and their armament, as may be seen from the following figures :—

BRITISH.

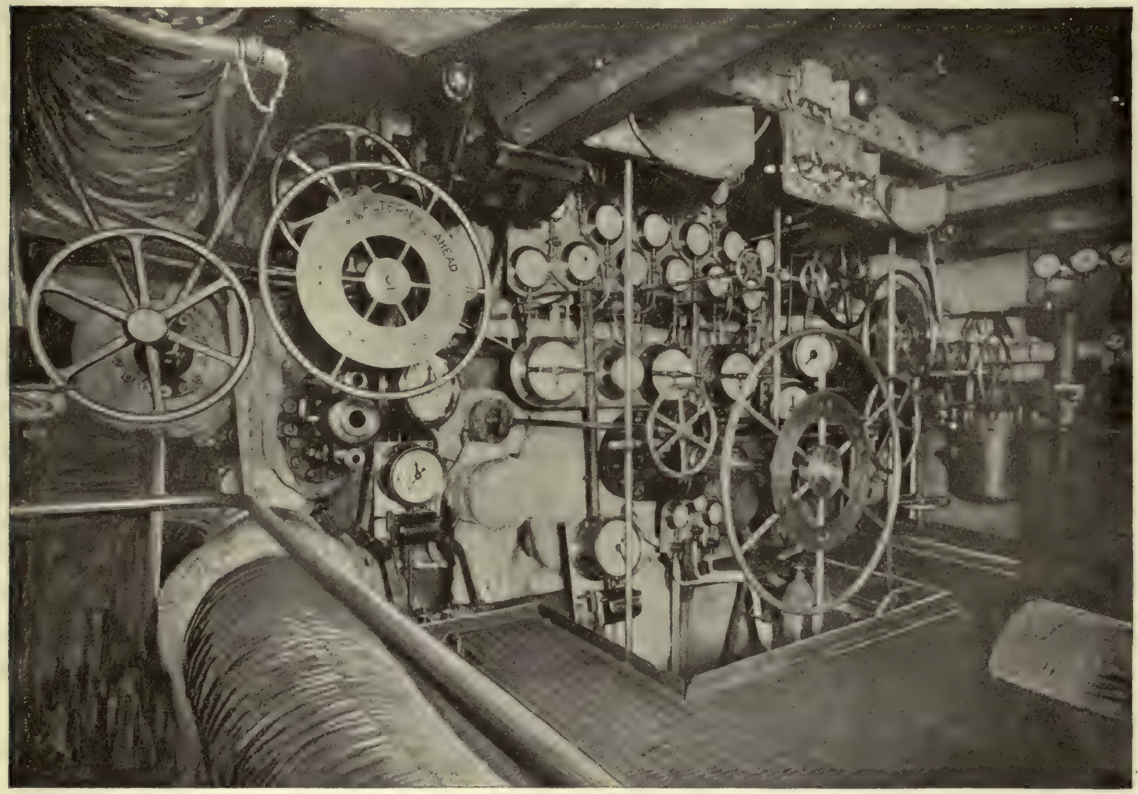
	Lightning.	No. 74.	No. 039.	No. 041.	No. 080.	No. 091.	No. 098.	No. 6.	No. 31.
Date of Launch...	1877	1882	1885	1886	1889	1894	1901	1906	1908
Displacement.....	27 tons	17 tons	40 tons	60 tons	85 tons	130 tons	178 tons	247 tons	280 tons
Length.	84·5 ft.	60 ft.	100 ft.	127·5 ft.	130 ft.	140 ft.	160 ft.	166·5 ft.	178·5 ft.
Beam	10·8 ft.	7·5 ft.	12·5 ft.	12·5 ft.	13·5 ft.	15·5 ft.	17 ft.	17·5 ft.	18·6 ft.
Draught........	5 ft.	3·6 ft.	5 ft.	6 ft.	5·5 ft.	7·5 ft.	8·4 ft.	5·8 ft.	5·9 ft.
Designed I.H.P...	460	170	500	700	1,100	2,400	2,850	3,750 (T)	4,000 (T)
Designed Speed ..	18 knots	17 knots	19 knots	20 knots	22 knots	23·5 knots	25 knots	26 knots	26 knots
Armament........	—	1 Machine	—	2 3-pr. Q.	3 3-pr. Q.	3 3-pr. Q.	3 3-pr. Q.	2 12-pr. Q.	2 12-pr. Q.
Torpedo Tubes. ..	1	2	1	4	3	3	3	3	3
Complement......	15	7	15	15	19	18	32	35	35
Coal Capacity	7 tons	1 ton	10 tons	18 tons	20 tons	25 tons	20 tons	20 tons, oil	30 tons, oil

FOREIGN.

	Kamore.	Calliope.	Penguin.	Söbjörnen.	G5.	Eliagot.	Goyaz.	Merino Tarpa.
Nationality.....	Japanese	Italian	Austrian	Danish	Dutch	Turkish	Brazilian	Chilian
Date of Launch.	1904	1907	1907	1898	1906	1904	1908	1902
Displacement...	150 tons	200 tons	197 tons	142 tons	144 tons	165 tons	150 tons	130 tons
Designed I.H.P.	4,200	3,000	3,000	2,300	2,000	2,200	3,000	2,000
Designed Speed.	27 knots	26 knots	26 knots	23 knots	25 knots	26 knots	26·5 knots	25·5 knots
Armament. ..	1 6-pr. Q. 2 3-pr. Q.	3 3-pr. Q. —	4 3-pr. Q. —	1 4·7-in. Q. 1 1-pr. Q.	2 3-pr. Q. —	3 3-pr. Q. —	2 3-pr. Q. —	— 3 1-pr. Q.
Torpedo Tubes..	3	3	3	3	3	3	2	2

It will be seen from the above tables how great an advance has been made in the last ten or fifteen years, and how even minor Powers with aspirations to naval strength are following the general upward trend in displacement and other essential features.

The torpedo boat of to-day is considerably larger than the earliest destroyer, whilst the latest development in this latter craft far outclasses the original torpedo gunboat. Indeed, the fusion of the "scout" and the "destroyer" is the natural outcome of existing development. Whether the future *rôle* of destroyers is to be that indicated by their



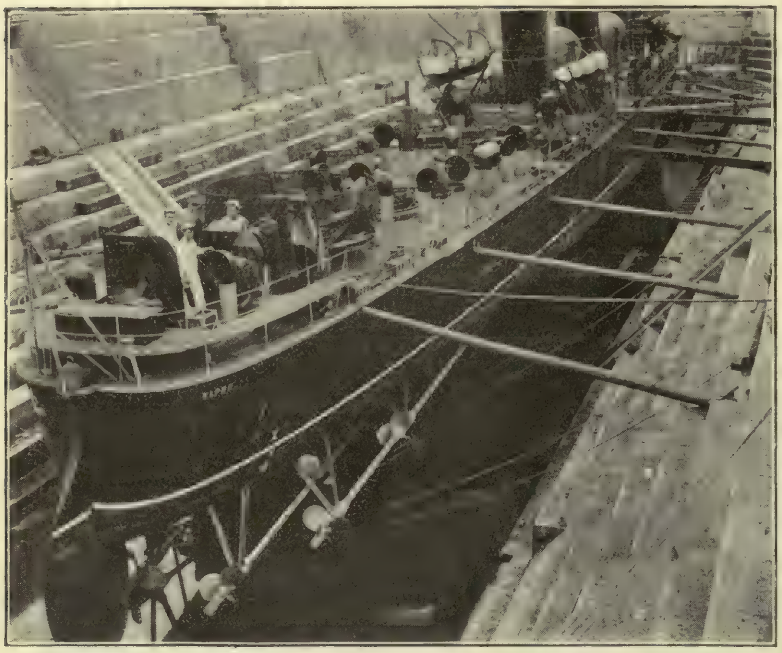
IN THE ENGINE-ROOM OF H.M.S. "TARTAR." (*Photo, Messrs. John I. Thornycroft and Company.*)

present name or by that of "scout" must in any event depend largely upon the admiral to whose command such craft are attached, and upon circumstances.

After this short account of the striking evolution of the torpedo-carrying boat, we will now describe a typical destroyer and a typical torpedo boat, and give, in addition, a few interesting and little known facts concerning both types. The fastest authenticated speed at sea by any existing warship is the 37·037 knots of his Majesty's ocean-going destroyer *Tartar*, which has steamed unofficially 40·2 knots, or nearly 46 miles an hour. The experimental destroyer *Swift* attained 38.3 knots on a short run, and the ill-fated *Viper* made a measured mile speed of 37·113 knots. The *Tartar* displaces 870 tons at a draught of water of 8 feet 8 inches. Her length is 270 feet, and her maximum beam 26 feet.

High Speeds.

By reason of their comparatively small size, destroyers cannot be very steady craft in a rough sea. In the older types a turtle-back shaped deck was given them forward, the idea being that, after diving into a head sea, the boat could readily shake off the mass of water mounting over her bows. In the later ships, such as the *Tartar*, however, the front part of the ship is built up high to make it rather rise to the waves. On this "raised



H.M.S. "VIPER" IN DRY DOCK. (*Photo, West and Son, Southsea.*)
This, the first of turbine-driven destroyers, made phenomenal speeds.

forecastle" is placed a small armoured conning tower, and above this again a narrow navigating bridge. Behind comes the mast, carrying a little platform for a 24-inch searchlight. On the deck, in front of the conning tower, are two 3-inch 12-pounder pedestal-mounted quick-firing guns, side by side, with their ammunition lying close at hand in open cages.

On a Destroyer.

Behind the raised forecastle are the funnel, ventilation cowls, boats, torpedo tubes, and the aft 12-pounder gun. The *Tartar* has four funnels, of which the two centre ones are by far the largest. She and all her class mount but two torpedo tubes. The third 12-pounder gun, also on a pedestal mounting, is raised on a low grid-platform in the stern to an elevation almost equal to that of those in front. In the 30-knot destroyers there is, right aft, a small bullet-proof steel shield with two glass sight-holes. This protects a hand wheel, whereby, if necessity should arise, the ship can be controlled from the stern. The *Tartar* carries no coal, her boilers being heated solely by oil, as described below. The whole class to which she belongs are wonderfully fast, and have all exceeded easily their designed speed of 33 knots. The *Tartar* herself maintained an average of 35·36 knots over a six-hours' run—a remarkable record for continuous steaming. Her Parsons turbine engines are of 14,500 indicated horse-power. Her cost and that of her sisters works out at about £145,000 for each ship. It is hard to realize that into a hull of under 900 tons are packed engines developing 2,500 horse-power more than do those of the battleship *Majestic* of 14,900 tons! Let us carry the comparison further. In the *Majestic* the ratio of indicated horse-power to tonnage is 0·8 to 1. With the *Tartar* the figures are 16·6 to 1. But high speed means much money, and whereas the cost of the *Majestic* worked out at £60 per ton, the price paid per ton for the *Tartar* was about £167.

Turning to torpedo boats, the latest development of these craft is undoubtedly the class formerly styled "coastal-destroyers," of which thirty-six have been built for the British Navy. Taking one of the first batch built by Messrs. Thornycroft and Company at Woolston, we find that the displacement is 215 tons, the draught 5 feet 9 inches, the length 166 feet 6 inches, and the maximum breadth 17 feet 6 inches. The cost is approximately £45,000, or £209 per ton. The speed designed with 3,750 indicated horse-power is 27 knots. In appearance the boat has much in common with her larger sisters, the destroyers, but differs in that there are

The Modern Torpedo Boat.

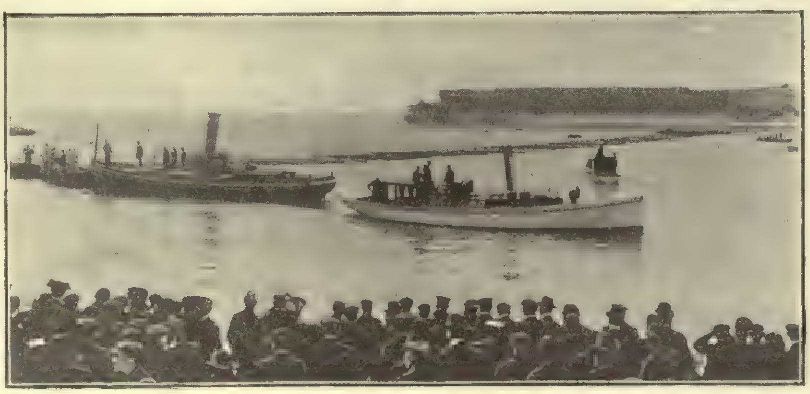
two funnels only behind the solitary mast, and that two 12-pounder guns, mounted one in the bows and one aft, constitute the armament. She carries three torpedo tubes, all capable of bearing on either broadside. The turbine engines are on the Parsons system. A maximum supply of 40 tons of oil, sufficient to steam 1,200 miles at 12 knots, can be accommodated. The speeds varied on trial from 27½ to 29 knots.

It will be interesting to glance into the engine-room of a boat of this type. Its most striking characteristics are roominess and comfort. The machinery is probably no lighter than that which would have been installed if reciprocating engines had been used, but the gain in comfort, safety, and simplicity is enormous. Otherwise, the engine-room does not contain any features very novel to turbine-fitted ships. The boilers are of the Thornycroft water-tube type, and are fired by oil fuel only. The system is one which has been developed by the Admiralty, and appears to work with very great success. The oil used is a thick, treacly substance, thoroughly atomized before combustion, so that the boat runs without smoke or smell, and the two funnels remain so cool that the paint on them is never affected. Oil-burning adds a little to the weight of the boiler installation, as a certain amount of fire-brick must be used, and this more than counterbalances the absence of metal fire-bars. The important point in the adoption of oil fuel is, however, the saving in *personnel*. So perfect are the mechanical devices fitted that it is said to be quite possible to run a vessel such as that under review with but one man in the stokeholds. In place of having to trim coal on to the stokehold floor, to shovel it into the furnace, and clean fires at intervals, the boiler attendant—he can scarcely be called a "stoker"—has only to manipulate his oil-feed and burner valves as required. The fire remains constant, and consequently the steam-pressure varies but slightly—this, of course, if the steam consumption by the engines be regular. The same regularity distinguishes the turbine engines themselves. In the old days of torpedo-boat trials a crowd of men hung around every moving part, and drenched the engines with lubricant to prevent overheating. All this bother is avoided by the employment of automatic lubrication, turbine engines, and oil fuel.

Oil Fuel.

The very latest types of fast small craft are due to the adoption of the internal-combustion engine for marine purposes. We possess a Yarrow built motor-vedette; and Austria has quite a fleet of small petrol-driven torpedo vessels capable of maintaining a speed of 22 knots. The British Admiralty are now looking carefully into the question of oil engines of various kinds with a view to utilizing them instead of steam in all small craft, and the evolution and development of this new type promises even better results than have been given us by the steam turbine.

Motor Craft.



BOOM ACROSS PORTSMOUTH HARBOUR TO EXCLUDE HOSTILE TORPEDO CRAFT.
(Photo, Russell and Sons, Southsea.)

FLOTILLA OF SUBMARINES AT GOSPORT. (*Photo, S. Cribb, Southsea.*)

THE GERMAN SUBMARINE "KARP" TRAVELLING AWASH. (Observe the mast-like periscope.)

SUBMARINE BOATS.

BY ALAN H. BURGOYNE.

THOUGH submersible craft have been adopted by nearly every first-class and second-class naval Power in the world, an air of mystery still surrounds them, and the secret of their functions is as hidden from the mass of the public as it was fifteen years ago, when France first adopted them as an efficient naval arm. It is remarkable that the submarines of to-day have more than twice the displacement of the early destroyers, while the speed of many of the latest is comparable with that of some battleships still included in modern fleets. The development of under-water craft was due to the practical and pressing need for a vessel capable of carrying out torpedo attacks in daylight. These boats can, owing to their invisibility when submerged, not only attack in the daytime, but retain with this power an advantage for harbour work at night over the fastest destroyer or torpedo boat.

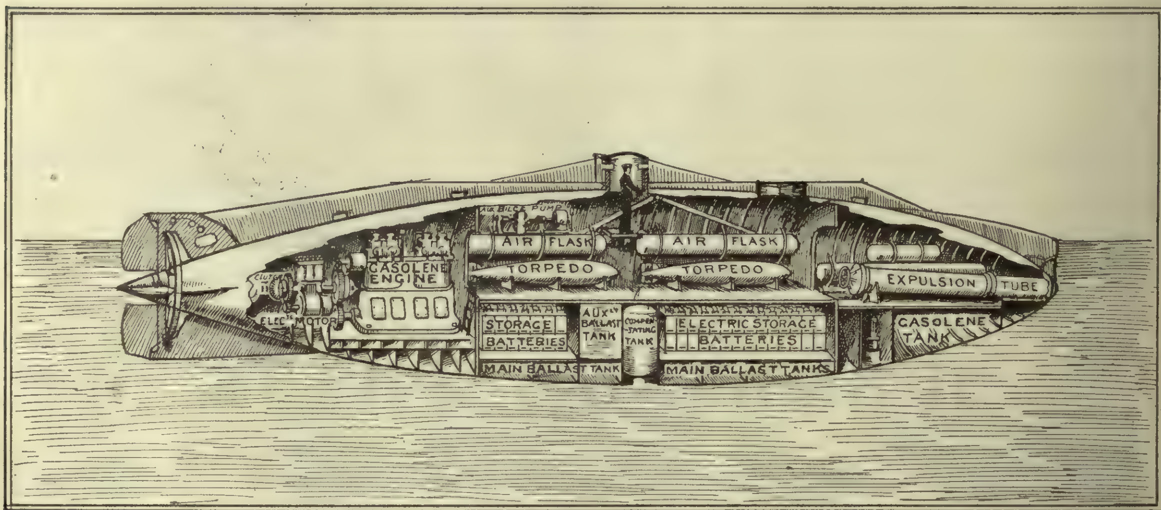
The British Navy of to-day boasts eighty submarines built, building, or projected. The earliest are designated No. 1 to No. 5. Then come thirteen of a larger and vastly-improved type—A1 to A13—displacing 180 to 204 tons. Next follow B1 to B11, possessing the much increased displacement of 314 tons. These have been succeeded by the C1 to C38, type, successful as regards sea-worthiness, speed, and offensive capacity. Lastly, we have the D class of 604 tons. The development from them onwards is likely to prove continuous and satisfactory. We will examine in detail No. 3, one of the first five built. (For obvious reasons details of the latest types cannot be given.)

Description of a Submarine.

The boat is shaped like a rather fat cigar, tapering towards its after or tail end. In front is a close-fitting cap, evidently covering a torpedo tube. In the centre of the top of the hull we see a small conning tower with a species of cut-water worked into the hull in front and behind. At the stern are the propeller (inside a circular guard) and a series of rudders for horizontal and vertical steering. So much an outside glance will show you.

Now to dissect the hull. This has a circular cross section from end to end. The plates

of which it is built up have a thickness in the middle of the hull of $\frac{8}{20}$ths of an inch, tapering to $\frac{7}{20}$ths towards each end. The length over all, from nose to point of propeller boss, is 63 feet

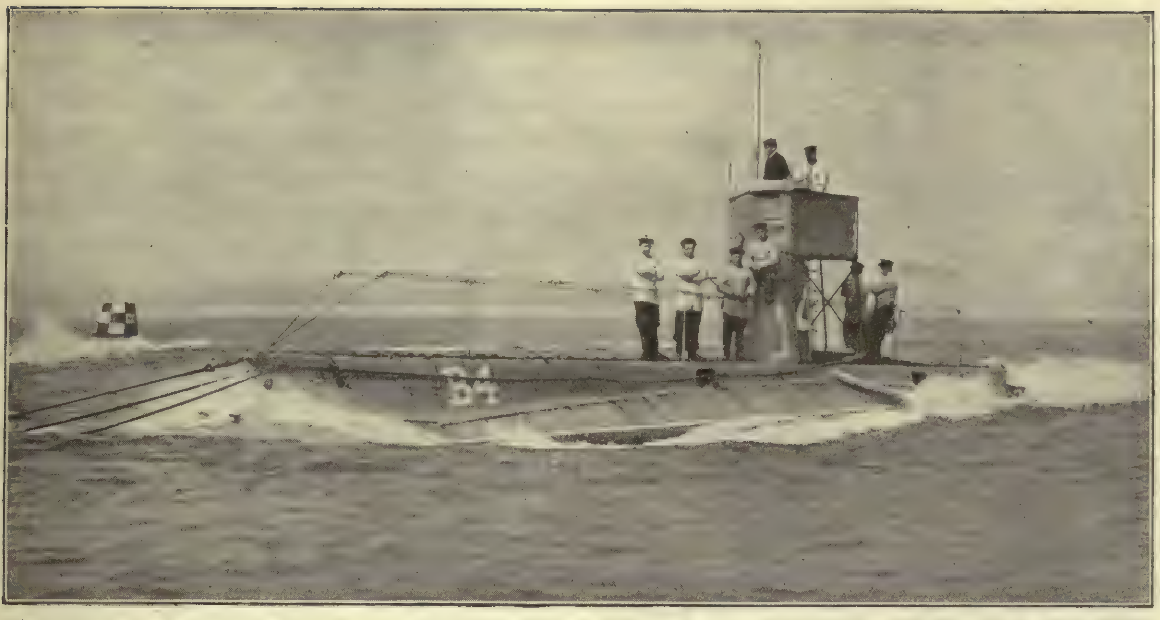


SECTIONAL VIEW OF THE INTERIOR OF A SUBMARINE.

4 inches, the beam or diameter of the hull at its largest section 11 feet 9 inches. The submerged displacement, and therefore exact weight of the entire boat, is 122 tons. The pressure on a submarine's hull, when submerged to a great depth, is very considerable, and to meet this external pressure the circular frames to which the hull plates are riveted are set only 18 inches apart, from nose to tail.

The various tanks which play so important a part in a submarine are placed under the deck and at the sides. These are (1) the "forward" and "after trimming tanks;" (2) the "main ballast tanks," separated by a longitudinal bulkhead; (3) "auxiliary ballast tanks;" (4) "gasolene tanks." The "trimming tanks" are receptacles of relatively small capacity situated at each end of the submarine. Prior to diving, it is necessary to regulate the "trim" of the boat, and, by the careful filling or emptying of these tanks, to obtain the proper equilibrium in the longitudinal sense. The "ballast tanks" are filled to reduce the submarine to a "diving" condition, when the conning tower alone shows above water, all surplus buoyancy having been negatived by the addition to the ship's weight of the water these tanks will hold. The boat, when thus prepared, can dive by the mere action of the horizontal rudders. In the "surface" condition, all superfluous water is ejected, and the vessel rides as high in the water as is possible. The difference between her surface and submerged displacement is the amount of her buoyancy. This buoyancy, the great safeguard in submersible vessels, differs very much in different types. The "auxiliary ballast tanks" are useful additions to the main tanks to replace an absent member of the crew. They have other uses that do not need to be detailed here. The "gasolene tanks" contain the fuel supply for the engines.

The low superstructure on the top of the hull is 31 feet 6 inches long, and 4 feet 5 inches wide. In its plates are riveted a number of cleats and rings for mooring-ropes and towing-hawsers. In the front, too, a small locker or cupboard is provided for a folding anchor and its chain. This superstructure is not water-tight, wide "scuppers" or holes being



SUBMARINE B4 CRUISING. *(Photo, S. Cribb, Southsea.)*

CONNING TOWER OF SUBMARINE B1, SHOWING STEERING GEAR AND PERISCOPE. *(Photo, S. Cribb.)*

provided along its lower edge to permit a ready entry of water when diving and an equally speedy emptying of the same at the surface.

The conning tower, a circular steel tube of 4-inch thick armour, has at its top a clear opening 21 inches in diameter, closed by a hinged steel cover, and made water-tight against a rubber gasket by a toggle-locking device similar to that often employed for fastening French windows. In the wall of this tower are a number of ports or peep-holes permitting an all-round view. They are fitted with thick plate glass, and provided with steel sliding covers to seal them effectually should the glass break under water.

Small as the hull is, it has at the forward end two bulkheads which can be rendered entirely water-tight. These are a necessary provision against collision, and are amply strong enough to withstand any inflow of water. Besides the conning tower, which is too narrow to allow a stout man to enter the boat, there are two additional hatches sufficiently large to admit machinery parts and torpedoes into the hull. Finally, the exterior presents no projecting parts which might be entangled with ropes, nets, or cables, etc.—a most valuable feature.

Means of Propulsion.

Turning to the means of propulsion, we find that the engine is of the internal-combustion type, and is driven by gasolene, of which 6,850 gallons are carried. The indicated horse-power, with the engines making 340 revolutions to the minute, is 160, and the consumption at this rate is one pint of gasolene per horse-power per hour. The four-cylinder engine drives a steel propeller shaft 4 inches in diameter through clutch gearing such as is found in a motor car. All the bearings are lubricated automatically. On the surface the speed of this boat is 9 knots an hour.

For running submerged, an electric motor, of the so-called "waterproof" type, developing 70 horse-power at a speed of 800 revolutions, is fitted. Whether submerged or awash, the vessel's speed is 7 knots. These two motors have each a double function. The gasolene motor is used (1) for driving the ship on the surface ; (2) for recharging the "storage battery"—when this is being done the engine is declutched from the propeller shaft. The electric motor (1) drives the ship either awash or submerged ; (2) starts the gasolene motor. The storage battery consists of sixty cells, and has a capacity of 75 horse-power for three hours. It need hardly be said that the battery and everything electrical within the submarine is carefully insulated from the hull. In addition to these motors there is an auxiliary electric plant of 10 horse-power for operating the bilge and tank pumps.

The air supply for various purposes is obtained from an air-compressor driven through gearing by the main electric motor or gasolene engine, as the case may be. Air reservoirs of 69 cubic feet capacity, and able to stand a pressure of 2,000 lbs. to the square inch, are provided. The air stored therein is used, amongst other things, for expelling torpedoes from the single tube forward, and emptying the ballast and trimming tanks.

Ventilation.

An important feature in a submarine is the ventilation. This is provided for most thoroughly in several ways. All the air-driven machinery exhausts into the interior of the ship. Excessive air pressure within the vessel is relieved by special safety-valves. Ventilators, with electrically-driven fans, are installed over the engine and at other suitable points to allow of complete ventilation when the boat is on the surface. The exhaust gases from the gasolene engine are led outside the boat through water-jacketed piping, carried aft along the hull, and set free under the superstructure at the stern.

A submarine must be provided with many gauges, and with instruments to record accur-

ately the depth, amount of ballast, gasolene, and air pressure, "trim" and "stability" of the boat, at any particular moment. The captain, who works the vessel when under way, has every device under complete control from his small platform beneath the conning tower. In the interior are bells, speaking-tubes, and, in the latest craft, telephones for communication between the navigator and the various parts of the boat. There are two compasses for navigating purposes, one located outside the hull, but observable from the interior of the conning tower, and the other in the conning tower itself.

Armament.

The armament consists of a single torpedo tube situated in the bows or forward part of the boat, its opening end 2 feet below the water-line when the boat is light. The tube is closed by a hinged flap, lifting upwards and operated by an air-cylinder, or by hand, at will, from the interior of the boat.

This concludes the description of a submarine of the early Holland type, from which have developed all the subsequent submersible craft of the American and British Navies.

Whilst we, however, have followed these particular lines, other nations have experimented for themselves, and the designs of ships accepted in their submarine fleets differ entirely and in almost every external particular from that described above. Internally they have most features in common.

What every constructor is aiming at is a vessel able to navigate on the surface like an ordinary ship, and to move beneath the surface of the sea in a direct line for the object it is desired to reach, while retaining stability in every sense, and remaining at all times under the absolute control of its commander. Moreover, it must possess the maximum of speed, safety, offensive power, and habitability, a trustworthy means of propulsion, and complete independence of all exterior help while in action.

Means of Submersion.

To submerge submarines from the surface condition three systems have been tried—those of (1) vertical propellers; (2) rudders inducing a descent on an even keel; (3) stern rudders sending the boat down at an angle, nose first. Vertical propellers, so placed that when revolved they draw or drive the hull beneath the surface, and, on being reversed, bring it to the top again, have been tested many times, without success, so the system may be dismissed as impracticable.

The second means of submersion—on an "even keel"—has many advocates. Here the horizontal rudders or diving-planes are so arranged that their action draws the ship under water without affecting her longitudinal trim. Many modern submarines dive in this manner. The system adopted for British and United States submarines of diving "by the head" makes use of horizontal rudders in the stern. These, affected by the water pressure set up by the ship's movement, dip the "nose" down and the "tail" up, causing a dive. The angle of descent is not steep, and the action of the rudders can be controlled to a nicety.

The means of watching from beneath the surface what is happening above are very limited, though improvements in the instruments employed are being made constantly. The "optical tube" (otherwise known as periscope, hyposcope, or cleptoscope) is based on the principle of reflecting mirrors placed parallel to one another at opposite ends of a long tube. Images of objects outside the boat and above the surface of the sea are cast on to the upper prism and reflected down to a mirror of parabolic section, which corrects distortion of image. The picture given is exceedingly small, and must be magnified. Were it not for the recent great improvements in the instruments used, particularly by the British Navy, their value would be slight indeed.

Many French "submersibles," as distin-

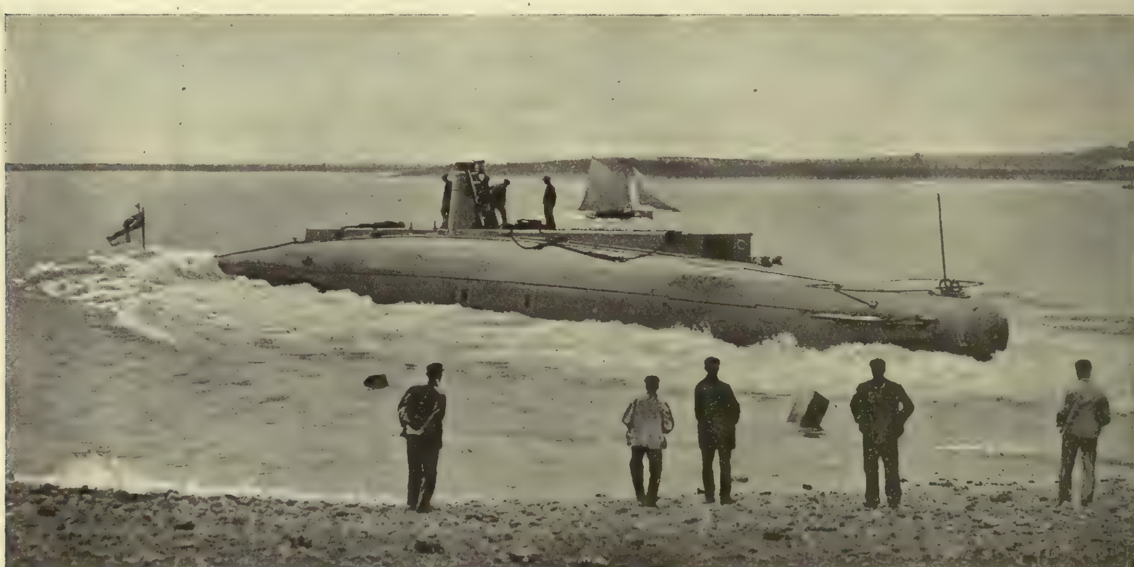
guished from "submarines" proper, are driven on the surface by steam engines, and it is well to note here that several submarines possess but one engine in place of the dual means of propulsion employed in our own boats. The rapid development of the internal-combustion engine, as regards power for weight, makes for immense advances in the speed of submarine craft. In the D1 we have already reached a horse-power of 1,200 and a speed of over 16 knots, and an even larger and faster vessel of her type is at the present moment being designed.

Armaments have naturally increased, and many of the modern submarines carry from four to seven torpedo tubes. Many of the French submarines carry two or more torpedoes slung in discharging cradles outside the hull. These projectiles can be released from within, the action of release simultaneously starting the engines. The time is certainly not far distant when we shall have the armoured submersible ship of 1,000 tons or more, carrying disappearing guns for surface work against surface torpedo craft, and a huge battery of torpedo tubes to attack battleships and armoured cruisers. Twin propellers, too, are now being fitted. Another feature receiving careful attention with a view to development is the microphone, which plays the part of a "mechanical ear," and warns the ship carrying it of the approach of either friend or foe, and makes it possible to gauge the distance and direction of the advancing vessel fairly accurately.

Improvements.

The form of submarines is altering considerably in favour of a nearer approach to the outward appearance of low-freeboard surface craft. "Bows" are being provided, as making for better surface speed, and sterns are being improved in shape. Displacements are continually increasing. It is interesting to compare the earliest with the latest submarines of various countries:—

		Displacement.	Speed.	Armament.
Britain	1902 (No. 3)	122 tons	8 to 9 knots	1 tube.
„	1909 (D1)	604 tons	16 to 17 knots	3 tubes.
France	1901 (*Français*)	139 tons	12 knots	3 tubes.
„	1910 (Q74)	810 tons	14 to 15 knots	6 tubes
Russia	1904 (*Delfin*)	200 tons	8 to 9 knots	4 tubes.
„	1909 (*Kaiman*)	500 tons	15 knots	4 tubes.
U.S.A.	1898 (*Holland*)	74 tons	8 knots	1 tube.
„	1910 (*Seal*)	425 tons	14 to 16 knots	6 tubes.
Italy	1894 (*Delfino*)	107 tons	9 knots	1 tube.
„	1908 (*Foca*)	230 tons	15½ knots	2 tubes.



LAUNCH OF A SUBMARINE. (*Photo, Messrs. Vickers Sons and Maxim.*)

PICKING UP A TORPEDO AT SEA. (*Photo, West and Son, Southsea.*)

TORPEDOES.

BY ALAN H. BURGOYNE.

THOUGH most people must have seen photographs of a torpedo, if not a torpedo itself, it is doubtful if many civilians understand how intricate is the internal mechanism of the steel missile that has been developed from the invention of the Austrian officer, Captain Luppis.

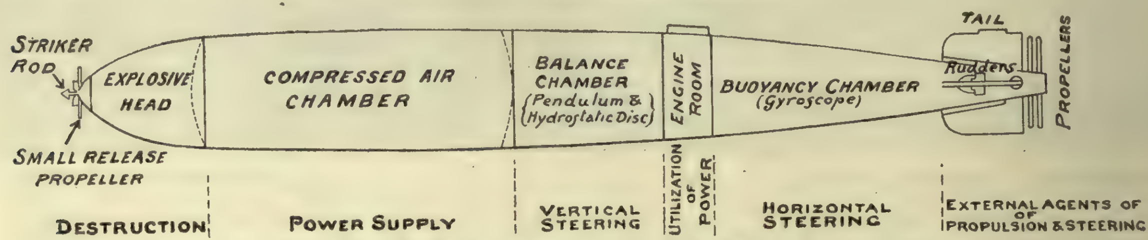
Externally a torpedo presents the appearance of a steel cigar, 16 feet 8 inches long, and having a diameter at its widest part of 18 inches. Its nose is very blunted, and, at its apex, carries a small, sharp-bladed propeller. Two-thirds of its length from the front small guide-flanges are fitted in the hull, and right at the tail are twin propellers, one behind the other, and revolving on separate shafts, one of which is placed within the hollow tube of the other. Then there are small horizontal and vertical rudders, which, through the movements of beautifully-arranged internal - balance mechanism, maintain the depth and direction of the torpedo after launching. Beyond these features, and sundry little holes, movable valves, and screw-heads laid flush into the steel skin, nothing noticeable is presented outwardly to elucidate the working of a torpedo. We may learn, perhaps, that the weight is 1,227 lbs.; that the speed for 600 yards is about 30½ knots; and that the effective range against moving ships is reckoned to be 1,000 yards. Of the total weight given above the charge of dry explosive carried in the nose weighs 188 lbs. Finally, we may be told that the cost of a torpedo, according to its type, lies between £200 and £500. So far so good. Now let us dissect the tube, and metaphorically cut it in half from end to end and see what is laid bare.

Divisions.

We discover six distinct and separate parts. Beginning from the nose, these are named as follows: (1) the head, (2) the air chamber, (3) the balance chamber, (4) the engine-room, (5) the buoyancy chamber, and (6) the tail and propellers. In times of peace the torpedo is fitted for practice purposes with what is called a "collision-head," made of thin copper and filled with water up to a weight equalling that of the "war-head." In these practices an indicating light, the Holmes light, is so placed inside the torpedo that, when the head collapses against an obstacle, the influx of water causes an immediate display of smoke and flame, making it a fairly easy business to

trace the projectile for recovery by night or by day.

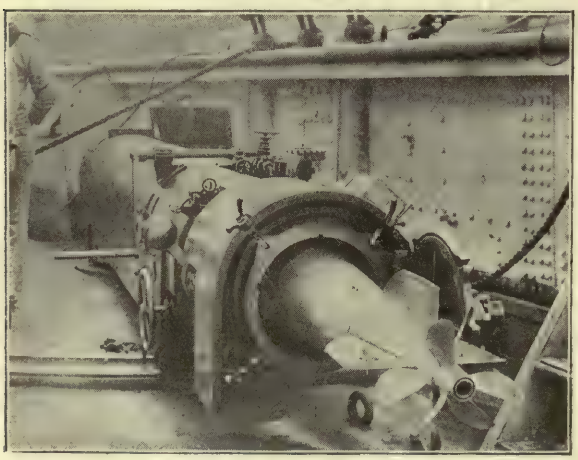
We now come to the forward end of the head—the small screw already mentioned. This is part of the safety device to prevent the accidental explosion of the torpedo before it has been discharged and is on its way towards the enemy. A torpedo is exploded by the force of its own momentum, which on impact drives a thin steel rod, projecting from the nose, into a detonator tube of fulminate of mercury. This fulminate, in its turn, ignites the dry charge just behind it, and causes an explosion of the whole mass of explosive in the main body of the head.



DIAGRAMMATIC SECTIONAL VIEW OF A TORPEDO, INDICATING ITS VARIOUS DIVISIONS.

Since a mere tap would fire off this enormous charge, three means of safeguarding against disaster are provided. First, there is a pin which, until withdrawn, prevents the operation of the other safety arrangements. In the excitement of a torpedo attack or a battle, it is conceivable that the withdrawal of this pin might be overlooked, and the result would be that the torpedo would rub its nose harmlessly along the hull of the enemy, or would be recovered in an innocuous condition from the meshes of the torpedo net. After one of the Japanese destroyers' raids outside Port Arthur, no fewer than eleven unexploded torpedoes were disentangled from the net of a single Russian battleship.

Safety Devices.



A WHITEHEAD TORPEDO PARTLY INSERTED IN DISCHARGE TUBE.

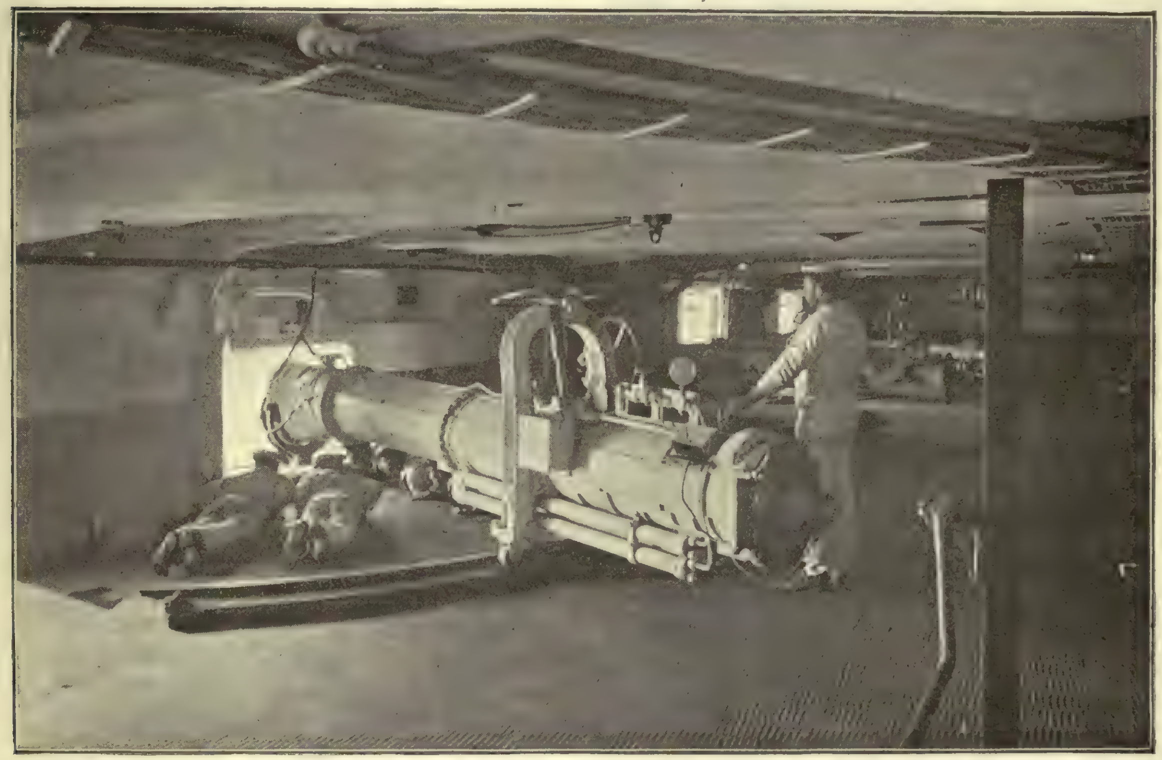
Note the hinged after portions of the horizontal fins for vertical steering, and the tiny vertical rudders in the same fins for horizontal steering. (*Photo, S. Cribb, Southsea.*)

Secondly, there is a small thumb-screw threaded along the striker-rod, which, if left screwed tightly home on the nose of the torpedo, prevents the rod from being driven into the detonator within. This also must be removed before firing.

Thirdly, and lastly, comes the little propeller of phosphor-bronze referred to above, screwed through the body of the pistol into the striker, thus locking the two together. When the torpedo has been fired, and has run, perhaps, a hundred yards, this propeller (the safety-pin having, of course, been already removed) is unwound by the action of the water as the torpedo is driven forward, thus leaving the striker free to be pushed back into the detonator. True, a small shearing-pin remains, but this is cut through by the force of the blow. A net-cutting device is worked into the propellor, and with this it is hoped wire nets may be pierced, leaving a hole

through which the torpedo shall continue its passage to the hull.

The charge itself consists of gun-cotton, either built up in sections shaped to fit the conical head, or else compressed into one solid mass which just fits the steel shell, and has a centre tube pierced for the reception of the detonator. When the head has been filled, a



READY TO DISCHARGE A TORPEDO FROM ITS TUBE. (*Photo, Gale and Polden.*)

thin containing plate is placed over the back of it, and it is fitted directly on to the next of the six sections—(2) *the air chamber*. This is a cylinder having walls from $\frac{1}{4}$ to $\frac{1}{3}$ of an inch thick, and capable of withstanding a pressure of 2,250 lbs. to the square inch. It is made of the very finest high-tensile steel, and only a few firms are entrusted with its manufacture. The result of the explosion of an air-cylinder charged to the enormous pressure used can best be left to the imagination. At the top of the rear end of the air chamber is a small tube—the supply tube—by which the air is led through a valve, which automatically keeps the feed pressure constant, to the engines.

At the back of the air chamber comes (3) *the balance chamber*. This contains the mechanism for keeping the torpedo at the depth at which it has been arranged to run. It would take too long to explain the principle in detail, but briefly stated the movements of the torpedo in the horizontal sense are controlled by the pressure of the surrounding water at various depths upon a very delicate movable "hydrostatic disc" in the wall of the outer hull. The disc is made water-tight by an india-rubber joint, and is pushed out by a spiral spring inside, which can be adjusted to equal the pressure exerted by the water at various depths. In conjunction with the disc a pendulum works according to the inclination of the torpedo. Both are connected with a "servo-motor," a

FIRING A TORPEDO FROM A DESTROYER. THE MISSILE NOT YET CLEAR OF THE TUBE.

(*Photo, Gale and Polden.*)

small auxiliary air engine entirely distinct from the main machinery actuating the propellers, and which is to a torpedo what the steam steering gear is to a ship. A half-ounce pull on the rod operated by the disc and pendulum is transmitted as a pull of 180 lbs. by the servo-motor to the horizontal rudders.

Behind the balance chamber is (4) *the engine-room.* This contains the propeller engines, servo-motor, and counter-gear for making range adjustments. The engines are of a type mostly constructed by Messrs. Brotherhood, develop 56 horse-power, and have three cylinders set at angles of 120° round a central shaft driving the rear propeller. Bevel-wheel gearing turns in the reverse direction a sleeve to which is attached the forward propeller.

Next in order comes (5) *the buoyancy chamber.* This small chamber contains the gyroscope, and provides the buoyancy of the torpedo. With the air chamber charged to a pressure of 2,250 lbs. to the square inch, and a dead weight of nearly 200 lbs. in the war-head, the buoyancy of a torpedo is a negative quantity. It is necessary in peace time that the torpedo should be recoverable after firing, and the expenditure of air during the run reduces weight sufficiently to ensure the projectile floating on the surface. But in war time the torpedo would be set to sink should it miss its mark, for it would be dangerous to allow so potent a weapon to float about the open sea when once the safety-pin has been removed from its live head. The torpedo's gyroscope, the principle of which is the same as that of the cheap toy sold under that name, weighs 15 lbs. in all, and its central feature, the wheel, weighs 1¾ lbs. This gyroscope is carefully suspended on gimbals in a vertical position and transverse to the axis of the torpedo. Attached to its own axis is a powerful steel spring connected with a toothed gearing, actuated by a rod attached to the air lever that starts the main engine. The effect of throwing back the air lever is to release suddenly the spring, which has previously been compressed by hand, with the result that the gyroscope is spun round at an enormous velocity—about 2,200 revolutions a minute. The gyroscope works a servo-motor actuating a pair of movable vertical rudders. If now the torpedo, from any cause, be deflected out of the line of fire, the gyroscope, by maintaining its axial position in the line of fire, acts on the servo-motor, and, by means of the vertical rudder, steers the torpedo back again to its original direction. The cost of each gyroscope, including the royalties attaching to its manufacture, is £50, no inconsiderable proportion of the value of a complete torpedo.

TORPEDO CLEARING ITS TUBE.

(*Photo, S. Cribb.*)

Last section of all is (6) *the tail section.* This contains the wheel-gearing for conveying the motion of the engine shafting to the propellers, the gear for providing reverse movement in the two screws, and the horizontal and vertical rudders. The fore propeller revolves in a clockwise, the after one in an anti-clockwise, direction, each counterbalancing the other as regards forces tending to revolve the torpedo.

The best torpedo in general use to-day has a speed of 35 knots for 1,000 yards, and 30 knots at 1,500 yards. With surface destroyers steaming at 37 or more knots in smooth water, this speed is no longer found to be adequate, and a description of a new development recently made public will be of interest to readers of this article. It is some years since the world was startled with rumours of extraordinary results having been achieved with the American Bliss-Leavitt apparatus for heating the air of torpedoes. From that time onwards the firm of Messrs. Whitehead and Company have devoted considerable attention to the investigation of this subject, and have now succeeded in producing a heater considerably more efficient than any yet tried. This *heater* consists of a small steel chamber between the air chamber and the engine of the torpedo, in which a certain amount of liquid fuel is burnt in contact with the air passing to the engine. The result is a gain in power of 100 per cent. The whole apparatus takes up about 3 inches only of the torpedo's length, and weighs about 12 lbs. Details of construction are, of course, known to the makers only, but they are such that no difficulty is experienced in handling the torpedo by any man acquainted with this weapon. In order to show clearly the advantages obtained by this new invention, the following table gives the speeds at various ranges of the very latest Whitehead torpedo when run cold and with heated air :—

Increasing the Range.

	With Cold Air.	With Heated Air.
Speed at 1,000 yards	35 knots	43 knots.
„ 1,500 „	30 „	40 „
„ 2,000 „	28 „	38 „
„ 3,000 „	23 „	32 „
„ 4,000 „	18 „	28 „

The British Admiralty has never been slow to adopt improvements in the torpedo armament of the fleet. For years Great Britain has led in the matter of submerged tubes for firing torpedoes, and our fleet practises with torpedoes more than any other in the world. An improvement of the kind described above is consequently of greatest value to our navy. Applying the result of the air-heater to advances in the projectile itself, we are now manufacturing a torpedo with a 21-inch diameter, a charge of over 300 lbs. of explosive, and an effective range of 7,000 yards.

We may mention briefly in passing a much smaller torpedo—the 14-inch weapon. This is now becoming obsolete, and its best speed is no more than 30 knots at 600 yards, whilst the explosive charge carried is only 77 lbs. It is still supplied to the smaller submarines of our own and other navies, but in the newest submersibles and in our own latest battleships provision will be made for the 21-inch torpedo only.

The American Bliss-Leavitt Company have developed a turbine engine for torpedoes, whereby 130 horse-power is developed from a machine weighing only 20 lbs. The turbine is air driven, and works in conjunction with the super-heater described above.

Firing Torpedoes.

Torpedoes are fired in two positions—from submerged tubes and from deck tubes. These tubes are similar in principle to guns, but, having merely to throw the torpedo clear of the ship's side, do not need the strength possessed by guns. The firing of torpedoes is accomplished either by a small charge of powder or by compressed air. When fired above water, the torpedo takes to its element almost parallel to the surface, though the method of

its discharge usually tends to lower the nose a trifle below the tail. In under-water discharge, if the ship firing the torpedo is in motion, a steel slide is pushed out from the side in such a manner that the torpedo, when fired, shall not be affected by the rush of the water along the vessel's hull. Torpedoes would not be fired from submerged tubes at our Admiralty. It was "controlled" by a pair of wires wound on two drums within the torpedo, and which, rapidly hauled upon from behind, revolved the propellers and drove the torpedo forward. Each drum actuated a separate screw, and at the same time, by a clever transmission gear, worked the rudders.

Controllable Torpedoes.

TORPEDO STRIKING THE WATER. (*Photo, West, Southsea.*)

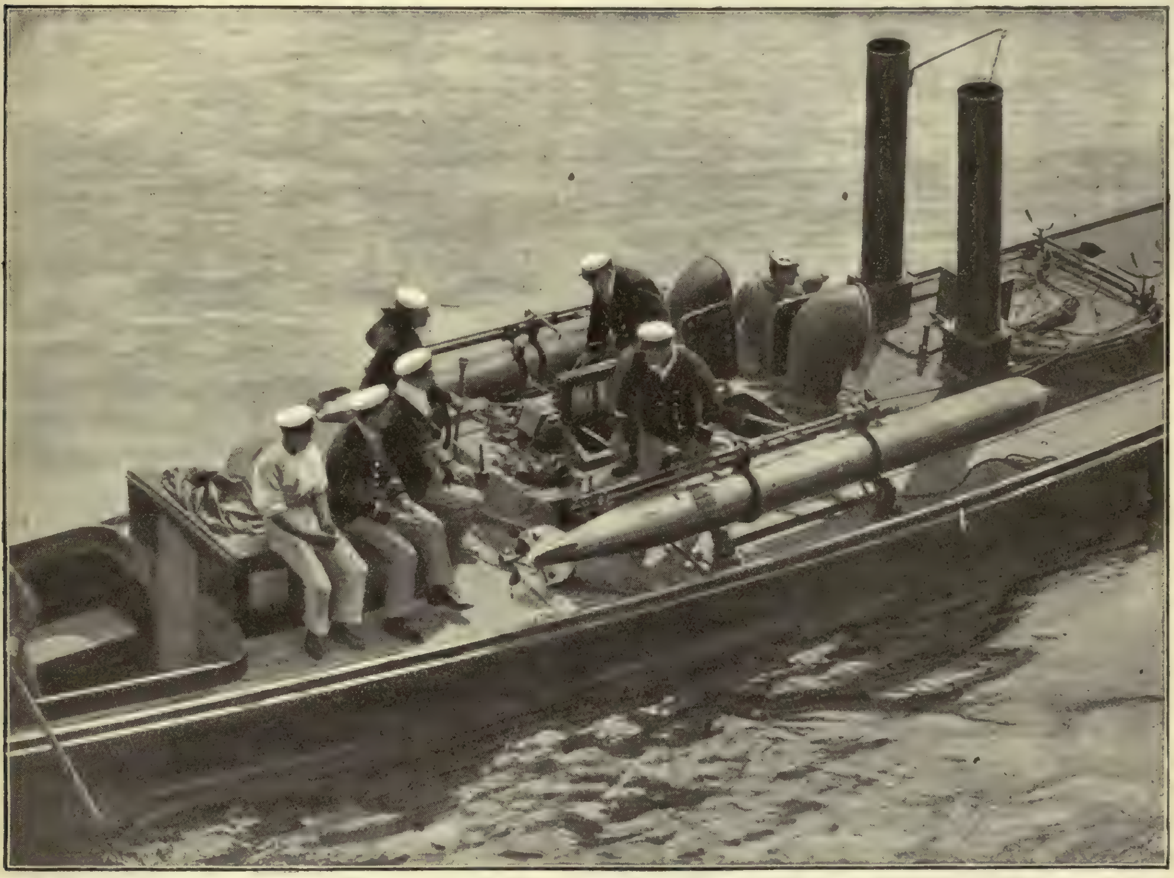
speeds exceeding 16 knots, and 14 knots is the maximum generally accepted to-day. The torpedoes employed by other nations are all derived from the Whitehead, though they have been given different names. We may appreciate with satisfaction, however, that, in the matter of torpedo evolution along progressive lines, Great Britain stands easily first to-day.

In addition to automatic torpedoes, attention has for many years past been devoted to "controllable" torpedoes. Of these the most famous is the Brennan, now abandoned by

If one wire were pulled faster than the other, the torpedo turned to the right, and *vice versâ*. The great fault of the Brennan torpedo was that it could not return to its starting-point, though it could twist or turn about in any direction over an arc of 40° each side of right ahead.

At the time that we were developing the Brennan, the United States purchased the Sims-Edison torpedo. This was a torpedo 28 feet long, suspended by four supports from a metal surface-float fitted with two small

masts whereby the track of the torpedo could be followed from the shore. Propulsion was obtained by electric power from the shore, conveyed to engines within the hull by means of 3,500 yards of thin cable stored on a drum



PICKET BOAT AND TORPEDO DROPPING GEAR. *(Photo, S. Cribb.)*

carried by the torpedo. Steering was done by means of electric magnets. The projectile, 21 inches in diameter, carried a 396-lb. charge of explosive. The entire weight of the apparatus was 4,004 lbs. Since the speed obtained was only in the region of 12 knots, the value to-day of this ingenious weapon cannot be considered great.

The discovery of wireless telegraphy, and the application of its principles to wireless electrical control, produced a number of inventions of a character far more likely to be adopted in modern fleets. Perhaps the best advertised of these is the "Actinaut" of Messrs. Orling and J. Tarbotton Armstrong. Here we have a torpedo, considerably larger than those at present made, containing within its hull an electrical engine, power chamber, steering mechanism, and war-head filled with explosives. It receives the power actuating the rudders through Hertzian waves, intercepted by a jet of water—thrown up at the head of the torpedo—in place of the wire-receiver usually fitted in such inventions, and which might conceivably be shot away.

Crewless Submarines.

A crewless submarine was recently constructed at the Creusot Works in France, and tested in the Gulf of Antibes. It is made up of two cylindrical vessels having cone-shaped ends, and displacing about 7 tons. The

TORPEDO INSTRUCTION ON H.M.S "VERNON."
(*Photo, Gale and Polden.*)

upper cylinder, which acts as a float, is 28 feet 6 inches in length, and has a diameter of 18 inches. On this cylinder are mounted two masts for supporting the receiving aerial wire at a height of about 10 feet; also to each mast is attached a coloured electric lamp for indicating the direction of the vessel at night. The lower cylinder is 36 feet in length, and just over a yard in diameter. It carries, besides the accumulator battery for furnishing electrical energy to the motors which propel and steer the boat, a launching frame for discharging a Whitehead torpedo. The receiving apparatus is placed in the superstructure of the boat. On oscillations being set up in the aerial wires, the receiving apparatus brings into action the motors for steering the boat, and for carrying out, through a small distributing switchboard, the various other duties that in a submarine with a crew would be done by hand. It is impossible to describe here in detail the technical features appertaining to this invention. It is sufficient to state that a single operator on shore was able to (1) start the propelling motor in the forward or reverse direction; (2) stop the motor; (3) steer the submarine in any direction around the compass; (4) light up either of the signal lamps separately or both together; (5) discharge the Whitehead torpedo carried.

A Mr. John Gardner of Fleetwood has built a most efficient little crewless submarine weighing a ton and a quarter. It is 16 feet in length, and is meant to protect harbours or roadsteads against large submarines. Its main feature is that cessation of the aerial current brings the boat to rest, so that if it gets beyond range, or if any part of the mechanism goes wrong, it comes to a standstill automatically.

Lastly, we hear of a torpedo which, after hitting its mark, fires a high-explosive shell from an internal gun into the unfortunate enemy. Experiments have already proved that the effects of a shell so discharged are very great indeed, and the gun-containing torpedo seems well worthy of development. A torpedo exploding outside a hull may have its effect practically negatived by the presence of the double-bottom or the close subdivision of the hull into water-tight compartments. If, however, a shell could be fired from a torpedo striking the thin skin-plating close to the engines or boiler compartments, the damage that such a projectile might do on penetration is almost incalculable.

Torpedo Nets.

The best defence for ships against attacks by torpedo craft is, of course, the gun. Torpedo nets for harbour work are almost essential, and the belief amongst certain foreign naval authorities that they are an encumbrance has been given the lie by the events of the recent Russo-Japanese War. The wisdom of their retention by our Admiralty was amply demonstrated by the negative results the Japanese obtained in more than one attack upon Russian ships protected with this form of defence. These nets are laid along a shelf around the ship's side, but as a rule do not extend right forward or aft. When it is desired to put them into position, they are swung outboard

on a series of booms, and rest in the water with their upper edges just above the surface. The operation of "out torpedo nets" occupies merely a few minutes in "smart" ships. Russia attempted armouring her ships below the water-line, and also provided them with longitudinal armoured bulkheads; yet there were three of them, the *Kniaz Suvaroff* and two sisters, sunk by the Japanese at the battle of the Sea of Japan. The flagship, named above, was struck by at least three torpedoes, and sank on the night of May 27, 1905, as a result. But, after all, the best defence against the torpedo is the annihilation of the craft carrying it, and we come back to the training of the man-behind-the-gun as the arbiter of naval fortunes. He, and he alone, will decide the next war, as he has those in the past, where guns or torpedoes have been in question.

NAVAL DIVERS PREPARING FOR A DESCENT. *(Photo, Gale and Polden.)*

BY ALAN H. BURGOYNE.

The Alarm.

A VISIT to a British battleship usually leaves the impression (upon the uninitiated) of a superb piece of destructive mechanism, ready at a moment's notice to commence the deadly work for which it was built. Theoretically this is so, for every commissioned unit of the British Navy is maintained on what is termed a "war footing;" practically, it is untrue, since a hundred operations have to be carried out speedily, exactly, and simultaneously before a vessel can actually commence fighting. Let us assume that a battleship of the *Dreadnought* type is steaming north in a time of presumed peace to join the main fleet lying, say, off Rosyth. Suddenly a "wireless" message arrives from the Admiralty in London announcing the unexpected outbreak of war, and, as this message is brought to the notice of the captain, a hostile ship of similar class is sighted on the horizon, approaching at top speed. Here you have a vessel unexpectedly called upon to engage an enemy in combat. The reason why an instance of this improbable description is taken is because, were a war anticipated, or had hostilities already broken out, all ships in the navy would have made many of the preparations for action which we are about to describe long before the first gun was fired.

A bugle sounds clearly throughout the length and breadth of the battleship, telling every officer and man that an action is imminent. "Clear lower deck!" "Clear ship for action!" are the calls, and instantly nine hundred men rush to every nook and corner of the ship, seemingly in aimless confusion, but in reality knowing each man of them the task allotted to him for execution. At one and the same moment a thousand things are being done. We will take the more important of these as they would present themselves to the eye.

Preparing for Action.

Around the boat deck, from steel davits, hang the cutters, galleys, and gigs—wooden craft likely to provoke a conflagration as the result of shell-fire, and forming, moreover, what a sailor would term "shell traps"—that is, unnecessary targets ready to stop and burst shells that might otherwise pass by unharmed. Had the declaration of war not been so sudden—a veritable "bolt from the blue" we may call it—all but the absolutely necessary boats would have been left in harbour, and the remainder would already be half filled with water and surrounded with splinter-proof rope hangings to limit to some

extent the effect of likely fire upon their easily ignited hulls. Now, however, it is too late. They are therefore swung off their chocks or shaped seats, their detaining ropes are sent spinning along the davits that hold them suspended by multiple wheeled pulleys, the entire fastenings are released, and hey presto! the boats are floating, free and alone, in the wake of their former home. The steel davits that had served for the smaller boats, and the weight of which does not preclude such an operation, will be unshipped and laid on the deck, or perhaps even slung into the sea, as dictated by the decision of the moment. All this time, too, the water securely lashed, as, too, are the anchors, chain cables, and articles of all kinds on the outer surface of the ship that might, by the remotest possibility, become loose (or, in naval parlance, "take charge") in the thick of the fight, when no hands could be spared to set the matter right.

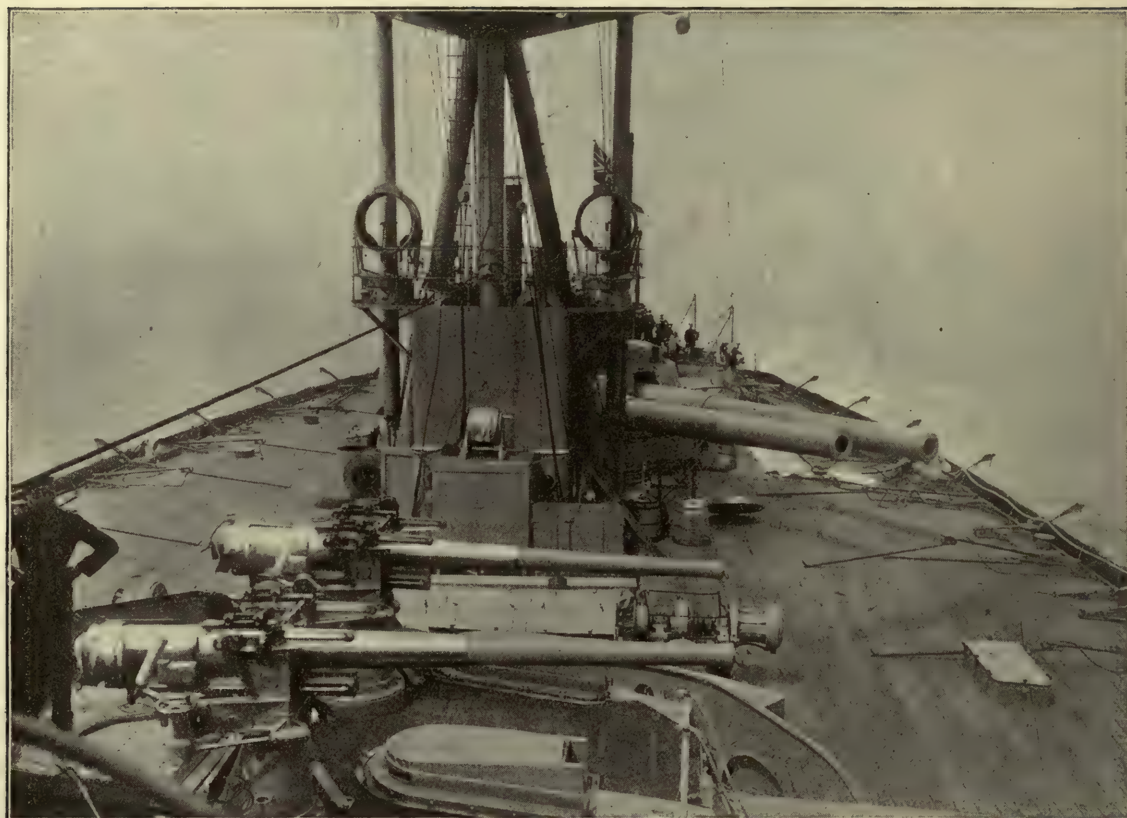
Splinter Nets.

Other men have been surrounding the bridge and other positions, where officers might find it necessary to stand for the better fighting of their ships, with thick, hanging fringes of rope and matting. These will form a fair protection against shell "blast" and splinters; for it is by no means certain

CLEARING DECKS FOR ACTION. *(Photo, S. Cribb, Southsea.)*

on each side of the ship resounds with the splash of useless wooden gear being cast ruthlessly away.

Elsewhere squads are flinging stanchions and protective side chains flat to the deck or swinging them outboard. They are then that a captain will prefer the protection of the conning tower to the greater freedom, though doubtless greater danger, of his bridge. The ship is now a mere skeleton of her former spick-and-span self; her contour, as she steams towards the foe—also preparing for



THE "DREADNOUGHT'S" QUARTER-DECK CLEARED FOR ACTION. (*Photo, S. Cribb, Southsea.*)

the coming fight, no doubt—will seem curiously skeleton-like and bare.

To this exterior clearance work, which is much in evidence, but, though necessary, by no means the most essential, succeeds the preparation of the fighting power of the ship. This is of two natures—the making ready of guns and torpedoes, and the organizing of complete and dependable readiness in the engine-room. A breakdown of the motive power of a battleship during a fight would prove almost as disastrous as the failure of the guns. To take the guns first. Whilst the gun crews in the barbettes are giving a final look at their weapons, fixing on the telescopic sights, testing the elevating, recoil, communicating, gun-cleaning, loading, turning, breech, and other mechanism, the men two or three decks below have opened up the magazines, and, after examining the fuses carefully one by one, have placed the various descriptions of shell—each being distinguished by a different coloured "nose" or "cap," such as yellow for "high explosive," red for "armour-piercing," white for "solid," etc.—in such a manner that they will be immediately ready for transportation to the "hoists," by which they are elevated to the base and breech of the gun being served.

In the Engine-room.

In the engine-room the engineer captain is testing personally all the working parts of his obedient giants; whilst his lieutenants supervise the oiling of this or that joint or part, and help in the stokehold or bunkers to encourage their men to maintain a full head of steam, so that, should the captain in his conning tower far above demand the maximum power from his ship, his engineers

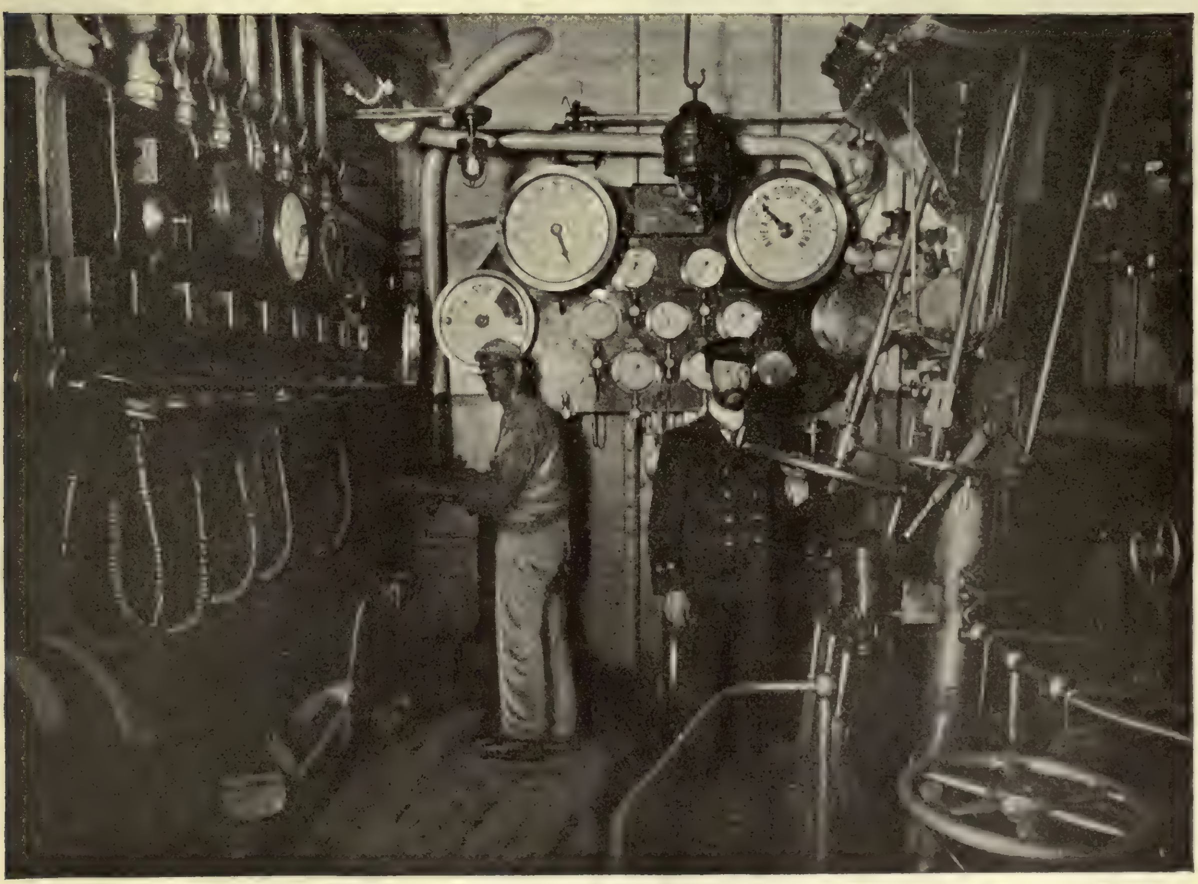
at least will not fail him. In the bunkers black figures toil on the coal, and "trim" it into form for the better service of the stokers, who, with a method that is provoking in its regularity, feed each furnace in turn, shovel-load by shovel-load. Following on the fire-feeders come those who clear away the ashes, so that the coal newly thrown in may burn with the greatest effect. These have two main tools—the "devil," a long hooked iron bar to stir up and level out the white-hot, roaring bank of coals; and the "rake." And down there, in a temperature of tropical intensity, sweating and faint, these men "devil" and "rake" for their country, as much heroes as any in that immense steel beehive.

In the torpedo flats, several feet below the level of the water, the torpedo crews are fixing on the war-heads, setting their shining weapons to run at the depth arranged, examining the safety catches, removing the safety pins, driving up the pressure in the compressed-air discharge cylinders, and, finally, sliding the steel cigars into the long metal tubes communicating directly with the outer sea.

In the Torpedo Flats.

An incidental work is that of the surgeons. If two are carried, arrangements are made whereby one can operate at each end of the ship; and, to meet the requirements that may arise, ward-room, gun-room, and even admiral's quarters will be turned into operating chambers or sick-bays for the wounded. Next, buckets of water and water-soaked oatmeal are placed in every corner of the ship.

Last of all comes a general testing of means of communication. The brain of the ship is



IN THE ENGINE-ROOM OF A BATTLESHIP. *(Photo, Gale and Polden.)*

The Conning Tower.

the conning tower, and therewith must every outlying part of the vessel be able to communicate. The three points in a vessel, upon the mutual inter-communication of which depends the success of the ship, are the "conning tower" (the nerve centre); the range-finders in the fighting-tops or "fire-control" platforms (taking their cue from the conning tower, and yet regulating the actions of the captain); and the "gun

INSIDE A CONNING TOWER. (*Photo, West and Son.*)

positions," which receive the order to fire from the conning tower and the range at which to fire from the range-finders, markers, and spotters. Complete co-ordination between these positions is essential, and free communication must at all costs be maintained. The conning tower in modern battleships is a circular or elliptical box of steel, with walls from 8 to 12 inches thick, based upon a steel tube communicating directly with the bowels of the ship, and descending far below the water-line. It has a shielded entrance, through which a stout man can scarcely crawl, and a hooded roof of great weight and strength, so fixed that narrow, well-protected sighting slits between it and the tower itself command an almost all-round view of the field of action. In the centre is the steering mechanism, the "helm-power" having been transferred hither from the wheel behind the chart-house on the exposed bridge above. Here will stand the captain, his commander, a midshipman or two, perhaps, and a signalman. Arranged around the steel walls are means of communicating with every part of the ship — telephones, speaking-tubes, electric buttons. An electric light signal-box communicates with the water-tight doors below, and the absence or presence of a red glow in this or that little window, several dozens of which make up the signal-box, tells whether all of these doors are securely closed or not. Around the inner wall of the conning tower, too, is painted a series of brightly-coloured horizontal lines, beginning and ending at different points. These show the captain the arcs of training of the various pairs of barbette guns. Thus, if in sighting an enemy during a fleet action he perceives that she and his line of sight cross, say, a green line marked BS, a scarlet line marked YS, and a white line marked ZS, he would know, if his ship were the *Dreadnought*, for example, that B turret starboard side could fire at the enemy, as could Y turret and Z turret, the S standing for starboard; also that the enemy could not be reached by the bow turret or the beam turret on the "port" or left side of the ship. The enemy, therefore, would be lying "behind the starboard beam."

All Ready.

These are the main features of the conning tower. The commander, upon whom devolves the entire task of "clearing ship for action," presently reports to the captain that all is ready. Incidentally it may be stated that all possible general precautions against fire are taken. Hoses are run along decks, and these latter, if time permits, are plentifully besprinkled with whitewash and damp sand. Also "splinter nets" and cordage are slung

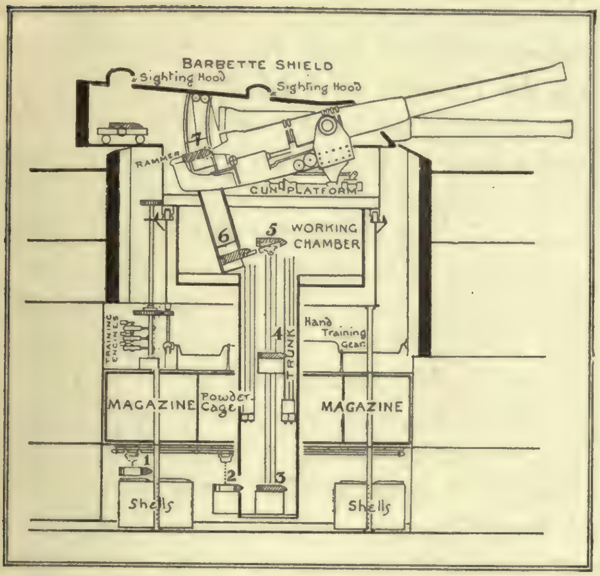


DIAGRAM SHOWING SECTION OF BARBETTE, BARBETTE SHIELD, TRUNK, AMMUNITION HOISTS, MAGAZINES, ETC.

The trunk, which descends to the magazine floors, is attached to the gun platform, and revolves with it. (Armour indicated by very thick lines.) The numbers 1, 2, 3, etc., refer to the successive stages in the transport of a shell from the magazine to the gun.

everywhere where their presence might help to prevent wounding by splinters.

The ship is now stripped ready for the fight; probably nearly all the crew are stripped to the waist also. Then the captain, having received a report from the chief of each department of his ship, and having had such reports finally confirmed by his commander, orders the bugler to sound "General quarters!"—the most moving call that is known. Instantly ammunition is whipped up the hoists and a shell placed ready in each gun. The officer in charge watches the indicator communicating with the telemeter or fire-control platform on the steel mast 80 feet up in the air above the deck. He is waiting for two things—the range, and the order to fire.

In the Barbette.

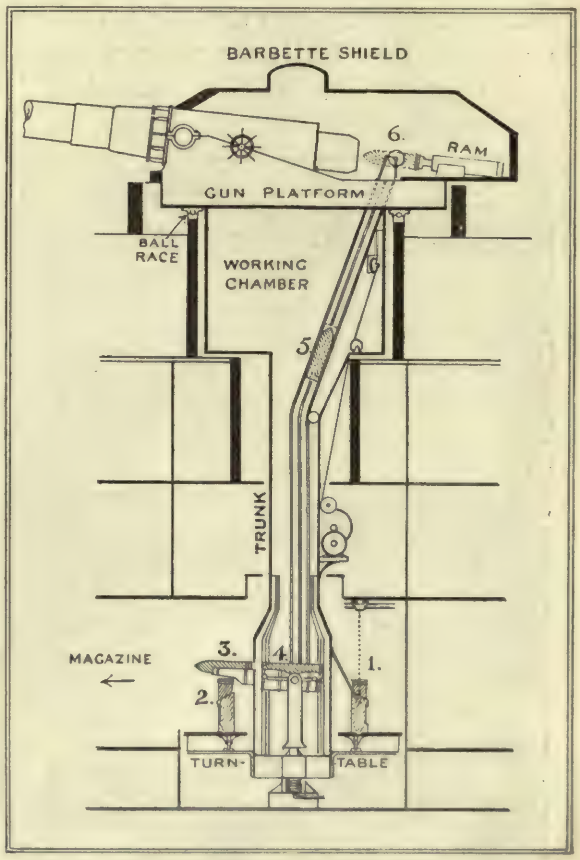
No. 1 at the gun, a skilled petty officer, has an eye glued to the telescopic sight, and a hand on the elevating and revolving wheels (see article on "The Armament of a Battleship"). Suddenly a report is heard forward—the sighting-shot—and immediately afterwards the range comes down, "10,800 yards." A trifling adjustment and the gun is ready for its deadly work. The gunner has got his "cross-wires"—the central feature of the telescopic sight—fixed carefully upon a spot just below the foremast of the enemy's vessel.

Then comes the word to fire.

A click, a sudden tightening of the air, a tremendous dull blow from everywhere at once, and a shell weighing 850 lbs. is speeding at over 2,000 miles an hour in the direction of the enemy.

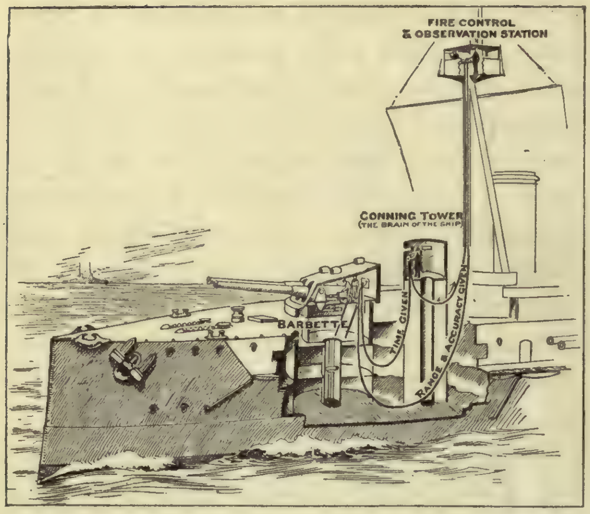
The action has begun!

From this time onward the pair of guns



ANOTHER TYPE OF BARBETTE AND AMMUNITION HOISTING APPARATUS.

Figures refer to the successive stages in the transport of a shell.



SKETCH TO SHOW HOW GUN-FIRE IS CONTROLLED.
The observer aloft gives the range and marks the shots; the captain decides the moment for firing.

in each barbette fire one shot each a minute. In practice they had done three a minute, but "Control and reserve your fire" is the order from the powers-that-be in the conning tower. Then comes a terrific blow on the immense steel hood of the barbette, an intense roar shakes the very firmament, and a deep bulge, glowing with heat, appears inside the huge steel plates.

A Hit.

A shell from the enemy has hit the shield —a large shell—and has exploded. The lieutenant in charge had been glancing through the sighting-hood: he drops like a log, his hands over his eyes, and his nose and ears bleeding. This is the penalty of war—he is deaf for life. Two other men have fallen around the gun. A few bolt heads have been crisply shorn off by the immense jerk of the impact, and fly with the power of rifle bullets across the confined space; thus one poor fellow is killed, and a second has a leg broken. No matter—it is the price of Admiralty, and a midshipman "carries on" the work of

FIRING A BROADSIDE FROM THE AFT BARBETTE OF THE "DREADNOUGHT." (*Photo, S. Cribb.*)

THE TORPEDO ATTACK.

his wounded senior. In swinging round the guns a point is reached where they stop; the roller bearings have been strained, and the young officer tells his captain up in the conning tower that he can only fire from right astern to a point or two before the beam. And they in the conning tower draw a white chalk mark across one of the horizontal coloured lines to correct the new arc of fire; whilst the midshipman in the barbette says, "Thank Heaven, the wires aren't cut," and, taking the range from time to time as it is sent down, goes on flinging 850-lb. shells into the enemy at the rate of two a minute—for he has a pair of guns to control —with as much coolness as if it were a game of bowls.

But down behind the armoured side is a man to whom the fight is nothing. He is surrounded by shooting blue sparks, coils, multitudinous wires, telephones, and, finally, a shell-proof, sound-proof (not quite, of course, but as near as can be made), worry-proof steel hut. He is the electrician in charge of the wireless telegraphy. From his little den a number of cables lead aloft to the many-wired antennæ stretching from mast-top to mast-top. If they should be shot away, a short-distance apparatus comes into operation;—there is no end to the ingenuity of man. At the moment he is in touch with the main fleet at Rosyth, and has informed the commander-in-chief that, though holding their own, a squadron of the enemy is running down to aid their battered consort. A dot-and-dash conversation ensues, as the result of which the British battleship is presently drawing north in the declining day to meet the reinforcements from the Forth.

The "Wireless" Operator.

Quickly the sun goes down behind the glassy sea, and a sombre moonless night covers with its pall the rolling battlefield. Yet the fight goes on, and the red flashes

IN THE WIRELESS TELEGRAPHY CABIN.
(Photo, Gale and Polden.)

of the hostile vessels break the darkness with sickening regularity. Our ship puts on speed—not to escape a fight, but because, being alone and having had many of her smaller anti-torpedo craft guns disabled, her captain does not care to risk an attack by hostile destroyers. The firing dies away, as its effectiveness diminishes owing to the darkness. Moreover, guns are apt to wear, and a careful captain thinks of these matters.

A hundred men are now on deck "clearing away the mess," and a further score are examining the 4-inch quick-firing guns to see how many have escaped unharmed. The commander presently reports that fifteen out of the twenty can be used, and gun crews are therefore told off to prepare them for the anticipated destroyer attacks.

Clearing Away.

Next in importance are the searchlights—three of these have been smashed to smithereens, but a sufficiency—ten, as a fact—still remain unharmed.

Whilst the anti-torpedo armament and the searchlights are being made ready, further squads of men are remedying as far as possible the damage caused in the action. Both of the huge funnels have been pierced many times by small projectiles. The holes are covered with thick canvas, so that the draught through the furnaces may not be interfered with. More serious has proved the explosion of a large shell against the leg of one of the tripod masts. The long steel tube has been badly shattered; so powerful wire cables are stretched from the searchlight platform—at the junction of the three legs—to steel bolt-eyes in the ship's side. These steady the mast, and take much of the strain off the injured part. The cables lessen the arc of fire of certain of the guns, but it is not expected that the larger weapons will need to come into action until repairs have been effected in a dockyard. After the essential and feasible repairs have all been carried out, the boatswain is told to "Pipe all hands to supper;" and for the first time since sighting the enemy's vessel the officers and crew take a "spell-O!"

Repairing Damages.

"Destroyers on either beam!" calls a strident voice. Even in peace manœuvres there is nothing so thrilling as a night attack. A shiver runs down the spine—the apprehension of the expected but seldom-seen. It is quite a relief to mark the dull-white bow waves tearing madly down upon you, for at least the tension is relaxed. These destroyers were sighted 5,000 yards away. As they are steaming at 30 knots, and, maybe, a little over, it takes them barely five minutes to arrive well within torpedoing distance. But five minutes of time have made history before now. Sixty seconds only have elapsed, when ten clear-carved shafts of brilliant, dazzling light dash out towards the oncoming destroyers. Two of them hover a second, then settle steadily on a thin gray form, and show up in clear relief the piling waters about the knife-edged bow and the coils of black smoke belching from the two squat funnels. As the lights stop on her she swerves to cut across their glistening edge and shows a quarter of her length. Simultaneously the guns commence their rattle, and soon all fifteen are pumping their 25-lb. shells into the enemy at the rate of ten each a minute. Our eyes are on the one destroyer—the first discovered. As we follow her progress we notice a black hole appear in her clear traced bows; another comes a little to the left, and smoke is seen issuing from it. The last shell to explode has set fire to something. Then the mast seems to stagger, and, after a shake or two, remains still again at a dangerous angle. Sparks, formerly pouring only from the tops of the funnels, are now rushing out from every part of them, from the deck upwards; and there are flames there too. The bow wave lessens; she is losing speed. At 1,000 yards she swings broadside on, and a hurrying crowd of men are seen clearing away a torpedo tube. It is now pointing this way. Then above us the 4-inch guns burst out with redoubled energy in angry protest, and a lucky shell hits the torpedo tube. An immense sheaf of flame bursts out—a red, hurtling mass of fire—and when it clears off the torn funnels of the shattered destroyer are seen just disappearing beneath the waves. "One!' counts the gunner at our side, and gently swinging his lean weapon round he pulls off ten fast shots at the next boat in the attacking flotilla.

The Destroyer Attack.

This is the destroyer attack.

But the odds favour the small craft. Rudely shaken by her fight, many of her small guns and searchlights shattered and unworkable, the battleship is in no condition to fend off the continuous and plucky attacks taking place from every side at once. A destroyer,

smashed and sinking, drives, by her very momentum, close enough to make sure of her aim. The torpedo shoots into the water on a wave crest, twice leaps clear of the sea before finding its depth, and then dives suddenly and hits the floating fort deep beneath the armour-belt. In a moment (and for a moment only!) all is confusion. A fountain of water hurtles up the side of the stricken ship, and as she shakes herself—resembling, it seems, some vast Newfoundland dog—her successful small foe disappears beneath the surface, riven in pieces by a hundred shells.

Ahead, signal lights flash out. Astern, the hostile ships are approaching. The captain has given all necessary instructions, and learns that though the water-tight doors hold all right, three compartments are flooded, the ship has a list of eight degrees to starboard, and she is two feet down by the head. No matter, his friends will now look after his foes; and as he drives his ship at 14 knots towards the Firth of Forth, the guns behind him tell of a night action just beginning. As he hands over the command to the navigating lieutenant, an intense weariness overcomes him. He has joined the flag and obeyed orders. "Carry on, Jones," he says; and he goes below to change the blood-soaked bandage about his head and to take a well-earned rest.

WORKING A 6-INCH QUICK-FIRING GUN.
The marines are in the "preparing to ram" position.
(*Photo, Gale and Polden.*)

A BRITISH BATTLESHIP OF THE IMMEDIATE FUTURE. DISPLACEMENT, 21,000 TONS; SPEED, $22\frac{1}{2}$ KNOTS; ARMAMENT, TEN 12-INCH, FOURTEEN 6-INCH GUNS.

THE WARSHIP OF THE FUTURE.

BY ALAN H. BURGOYNE.

WHEN efforts are made to probe the future, we are frequently told that supposition is a folly and prophecy a madness. In an attempt to forecast the possible evolution of warship types, we have at least deduction to help us. The trend of modern ideas in regard to battleships is fully evidenced in the suggestion of the eminent French constructor, Maximé Laubeuf, who speaks of 26,000 tons displacement and eighteen 12-inch guns for a future battleship; while the equally talented Italian naval constructor, Colonel Vittorio Cuniberti, suggests guns of 16·25 calibre or upwards for his ideal battleship of the immediate future. That battleships will increase in size, speed, and power to an extent as yet undreamt of is no longer doubted. Even a temporary reaction towards more moderate displacements—a reaction that might well be brought about by the endeavours of an active "too-many-eggs-in-one-basket" school—cannot affect the inevitable. It is well to emphasize the fact that but one thing can set a limit to the size of battleships—that is, the depth of water in harbours. Docks and money are not to be considered. The former are constructed to take ships, not ships to fit docks. Money also can be ignored. Doubtless in time the two million prime cost of the *Dreadnought* will increase to eight or more millions per unit. All nations whose purse proves inadequate to meet this drain will drop out of the contest for supreme power at sea, and leave the running to their richer opponents. This is the true national game of "beggar-my-neighbour," a game that has been

A BATTLE FLEET OF THE FUTURE.

In the foreground, a funnel-less, gas-engine-driven battleship of 33,000 tons displacement, and 51,000 horse-power; speed, 23½ knots; ten 16·25-inch guns, all firing on broadside. In the background, special vessel with elevated deck for the accommodation of airships and aeroplanes.

at the root of the rise and fall of every empire. Admiral Paris, one of France's most distinguished naval writers, summed up this question concisely. "The further we go," he wrote, "the more will naval war be waged with money rather than with men."

Hence we may anticipate vast vessels of 40,000, 60,000, or even double that tonnage, carrying an armament of one-calibre guns of huge size, and steaming at far greater speeds than are at present accepted. Increased displacement makes for greater steadiness of platform, and hence for better shooting in rough weather. Also it permits a higher freeboard, while giving a better "command" to the guns. A uniform or one-calibre armament simplifies the "spotting" of shot fired at an enemy, and therefore the training of the gunners, and renders the service of ammunition very simple. It permits the concentration upon a single floating platform of a "main" armament formerly spread over two or three units. High speed gives tactical superiority over slower vessels, and the power to run down and, by reason of the stronger armament carried, to crush hostile armoured cruisers or battleships of an earlier or slower type. The *Dreadnought* is of 17,900 tons, 21 knots speed, and carries ten 12-inch guns. Already we have the *Neptune* displacing 20,250 tons, and the natural

THE LATEST UNITED STATES "DREADNOUGHT," OF 26,000 TONS DISPLACEMENT. LENGTH, 545 FEET; DRAUGHT, 29 FEET; BEAM, 92 FEET; HORSE-POWER, 33,900; SPEED, 21 KNOTS; ARMAMENT, TWELVE 12-INCH, SIXTEEN 5-INCH GUNS; COMPLEMENT, 1,100 OFFICERS AND MEN.

In the three lower cuts this vessel (to the left) is compared with the *North Dakota* of 20,000 tons and the *Connecticut* of 16,000 tons.

(*Photo, Copyright, 1909, by Munn and Company. Reproduced by courtesy of the "Scientific American."*)

immediate development would be a ship of 25,000 tons, 23 knots speed, and carrying ten 13·5-inch guns. From this we shall reach by easy steps an immense funnel-less floating fort, steaming 35 or more knots, fitted with internal-combustion engines, mounting eight or ten 16·25-inch guns, heavily armoured, and with all steering and range-finding arrangements fitted below deck. This foreshadows the future "capital" ship as deduced from past evolution.

Of smaller ships it is more difficult to speak. The modern desire is not to multiply types beyond necessity, and whilst the armoured cruiser and battleship tend to amalgamate, the scout and large destroyer are similarly losing their identity in a single class. Speed will govern advance in all smaller craft, submarine or otherwise, but on the development of the former great hopes are based, and we may well see a submersible vessel of several thousand tons, a heavily-armoured deck, a speed of 30 knots, and an armament of twenty or more torpedo tubes. The fast motor vedette will replace the obsolescent steam torpedo boat of 100 tons and under, and, thanks to its speed and immunity from "sparking" at night, might conceivably be of great service in coast defence work. We are only on the fringe of high speeds, and may safely look for ships of 50 or 60 knots in the not distant future. The place of the torpedo remains in some doubt, but designs for a 30-knot torpedo cruiser (a glorified destroyer, in fact) of 15,400 tons, and armed with thirty tubes and two dozen small quick-firers, have been completed for the French Navy: it is doubtful, however, if it will mature. The protected cruiser is dead or dying—the fate of the armoured cruiser hangs in the balance; in the opinion of many people this type has seen its day. Four types, then, would seem to be likely developments of modern ideas and opinions. (1.) The *capital ship*, with huge displacement, complete armoured protection, the highest possible speed compatible with these two essentials, and a uniform armament of the largest guns. (2.) The *scout*, of moderate to large displacement (when the battleship is 55,000 tons or more, 10,000 to 15,000 tons will not be immense!), moderate protection, very high speed, and an armament of light guns. This type will embrace the destroyer. (3.) The *submarine*, of comparatively small tonnage, the highest surface speed possible, a large torpedo armament, and, perhaps, a few guns, on disappearing mountings, for surface work. (4.) *Motor vedette boats*, as small as circumstances permit, very speedy, and carrying one or two torpedoes.

Two facts not generally recognized are worthy of mention. One is that, as types evolve and increase in size and speed, the cost of shipbuilding per ton advances enormously; the second that, although the British ton cost follows the general upward trend, the ratio of difference in regard to British shipbuilding remains consistently cheaper. The obvious lesson suggested is that if we courageously make up our minds to buy a position of permanence as leading naval Power, we shall be able so to do. No nation, to whom it is a national necessity to maintain vast land forces in addition to a fleet, could long stand the strain of a contest waged along these lines. As warships increase in size and cost, so will they, in like ratio, decrease in number. Thus the great expensive ship-of-war will draw a definite line of demarcation between the first-class naval Powers and the rest, proving conclusively that with the navy of big ships lies the victory of the future.

END OF VOLUME I.

TA 15 W5 v.1

Williams, Archibald
Engineering wonders of the world

Engin.

PLEASE DO NOT REMOVE
CARDS OR SLIPS FROM THIS POCKET

UNIVERSITY OF TORONTO LIBRARY